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NAVAL SHORE ELECTRONICS CRITERIA

ELECTROMAGNETIC COMPATIBILITY AND ELECTROMAGNETIC RADIATION HAZARDS

DEPARTMENT OF THE NAVY
NAVAL ELECTRONIC SYSTEMS COMMAND
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FOREWORD

This handbook presents engineering material concerning electromagnetic compatibility (EMC) and electromagnetic radiation hazards (RADHAZ) to be used as a guide during the planning of a new installation or in the addition of equipments to existing facilities. Its purpose is to acquaint the reader with the effects of the interactions of electromagnetic radiation (EMR) with materiel and personnel from both an interference and a hazards viewpoint, to provide means of predicting such effects, and to enable the reader to plan for the elimination or protection of such potential interactions where necessary. To achieve this purpose, the book describes NAVELEX programs dealing with EMC and RADHAZ, provides basic background material, prediction techniques, evaluation and measurement techniques, and design and installation practices to achieve equipment compatibility and a hazards-free environment for naval shore installations.

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CHAPTER 1

INTRODUCTION

1.1 PURPOSE

This document (one of a series of Naval Shore Electronics Criteria Handbooks) contains technical data related to the fields of Electromagnetic Compatibility (EMC) and Radiation Hazards (RADHAZ). The purpose of the handbook is to provide technical guidance to system planners, engineers, and other personnel concerned with the planning, design, and installation of base electronic equipment and systems. Therefore, data and information in this handbook is organized and structured to achieve overall system compatibility by minimizing equipment interplay (cross-coupling), and to provide a RADHAZ-free environment for both personnel and materiel. To accomplish these goals, the handbook contains informative material and general design criteria covering the nature of Electromagnetic Radiation (EMR) and its effects upon biological systems (personnel) and materiel (electronic equipment, fuels, ordnance), interference reduction techniques, measurements and instrumentation, controlling the effects of EMR from a systems viewpoint, prediction and modeling techniques, and methodology for protection of materiel and personnel from radiation hazards. The handbook may be used both in new-site planning and in existing-site expansion efforts for the following purposes:

o Identify potentially interfering systems and potentially hazardous areas.

o Establish a control program slanted towards the elimination or minimization of such areas.

o Implement the control program by means of standardized techniques.

o Provide safety precautions based on the given criteria in those cases where hazardous areas cannot be eliminated.

1.2 IMPORTANCE AND SIGNIFICANCE OF EMC AND RADHAZ

The importance of EMC and RADHAZ becomes apparent when one considers the possible effects of electromagnetic energy upon people and materiel in light of the development and use of unprecedented high radiated power outputs, increase in equipment complexity and siting density, and the critical over-crowding of the electromagnetic frequency spectrum. Some of the known effects include:

o Total or partial destruction of electronic equipment.

o Inadvertent fuel explosions.

o Inadvertent ordnance triggering.

o Physiological damage to the human body.

o Degradation of equipment functions.

Thus, it appears appropriate that a uniform, coordinated body of knowledge be applied toward the study and reduction of the effects of electromagnetic energy in its interactions with functional systems and components. In this regard, people may be thought of as biological functional systems, with the RADHAZ problem then considered simply as the incompatibility between radiation-producing equipment and personnel.

1.3 BACKGROUND

1.3.1 Electromagnetic Compatibility

Prior to World War II, reports of interference problems were infrequent mainly because of the limited types of equipment in use during that period: radar and communications sets operating at relatively low power outputs and spaced far apart formed the major classes of electronic equipment then in general use.

World War II fathered the technological explosion resulting in more complex radar, sonar, communication systems, navigation, and countermeasures equipment. Increasing transmitter powers and receiver sensitivities brought increasing reports of "radio frequency" (as it was then called) interference at shore activities. including reports of interference from "new" sources such as fluorescent lights, rotating machinery, etc.

The problems created, spurred work during the 1940's aimed at determining the nature of radio frequency interference and achieving "after-the-fact fixes" by trial and error methods.

In the 1950's, studies of a more theoretical nature were undertaken, leading to experimental work on such interference reduction techniques as grounding, shielding, and filtering. New test equipment was developed at an accelerated pace. The interference problem became more acute with the appearance of megawatt systems and the problem of radiation hazards to personnel, ordnance and fuels greatly increased, as well.

The late 1950's and the 1960's brought a new phase, which may be called the beginning of Electromagnetic Compatibility, in which there was an awareness that the problem should be attacked at the planning and design stages of both sites and equipment, rather than after installation of the equipment. Initiation of attempts to predict potential interference and hazard problems during the planning stages began at this time, e.g. the Department of Defense Electromagnetic Compatibility Program, and its focal point, the Electromagnetic Compatibility Analysis Center (ECAC) were established to help coordinate efforts in these areas for the military services. Other groups concerned with EMC were formed, such as the IEEE EMC Group, the Electronic Industries Association, and the Society of Automotive Engineers (SAE) EMC Groups.

Current activity in EMC is centered on the use of modern computer analyses for modelling and prediction, management of the frequency spectrum, and control of electromagnetic radiation and conduction from an overall systems viewpoint.

1.3.2 RADHAZ

The radiation hazards problem has gone hand-in-hand with the trend towards higher output power and increasing equipment siting densities. Average radiated power has increased from about ten watts in 1940 to today's megawatt powers.

Early workers in the field of microwaves first noticed the heating effects on people by microwave radiation. Experiments with animals exposed to radiation subsequently demonstrated the insidious effects on tissue; some of the more pronounced effects being the formation of cataracts and testicular deterioration. As a result of these findings, attempts were made by many researchers to determine and establish safe hazard levels.

By 1958 a general agreement was reached establishing a power density level of ten milliwatts per square centimeter as the upper limit for constant exposure to microwave radiation, independent of the radiated wavelength. Further research (and experience) revealed that electromagnetic fields could cause inadvertent detonation of explosive devices, explosion of fuels, and damage to electronic equipment.

To control these hazards, programs were established within the Department of the Navy to define potential hazards, determine the degree of equipment susceptibility, and provide protection criteria and techniques.

Today, a new awareness exists that EMR is a national problem concerning commercial enterprise and the public at large, as well as the Military. This is emphasized by the recent establishment of a new Federal Agency, the Environmental Protection Agency. Of its many responsibilities, one will be to monitor and apply standards to define and control the inadvertent emissions by microwave devices used by the U.S. public.

1.4 DEPARTMENT OF DEFENSE ELECTROMAGNETIC COMPATIBILITY PROGRAM

The DOD Electromagnetic Compatibility Program (EMCP) was established to ensure EMC of all military Communication-Electronic (C-E) equipments, subsystems, and systems from conception and design through acquisition and operational phases. The program is an integrated DOD effort that assigns specific and joint responsibilities to DOD components in each of the program areas of standards and specifications, measurement techniques and instrumentation, education for EMC, data base and analysis capability, design, concepts and doctrines, operational problems, and test and validation capability. DOD DIRECTIVE 3222.3, OPNAVINST 2410.31, NAVMATINST 2410.1, and NAVELEXINST 2410.1 describe the various Navy programs which implement and support the DOD program, state Navy policy, and assign responsibilities for accomplishing the program objectives.

1.5 ELECTROMAGNETIC COMPATIBILITY ANALYSIS CENTER (ECAC)

This joint DOD activity, managed and operated by the Air Force, maintains the data bases and mathematical and computer analysis techniques for investigation of DOD and interservice EMC problems. It provides DOD components convenient and rapid access to the data bases and analysis techniques and assists in intraservice problems. As the DOD focal point of joint analysis for the EMCP, this facility analyzes C-E equipment and equipment under development, or proposed for development, to determine its EMC with other equipments in present and projected environments.

1.5.1 Data Base Files

The data base is a compilation of environmental information regarding both military and non-military fixed and mobile C-E equipments, selected technical characteristics of such equipments, and selected terrain elevation information.

a. Environmental File. This file represents a large part of the data base and contains technical information, operating characteristics, and site information related to government and non-government fixed site C-E equipments. The file is developed from military and non-military field surveys and from data provided by such agencies as the Federal Communications Commission (FCC) and the Interdepartment Radio Advisory Committee (IRAC). It contains the geographical location of the equipment, the operating agency to which it is assigned, operating frequency, operational duty cycle, antenna orientation, carrier modulation characteristics, and items of a similar nature.

b. Equipment Characteristics File. This file contains general technical performance and nominal characteristics data on specific equipments in both the military and non-military inventory. It is compiled by the ECAC from technical manuals, technical orders, test reports, and other sources, and includes such information as transmitter power output, receiver sensitivity, transmitter and receiver modulation and bandwidth capabilities, tuning ranges, etc.

c. Terrain Data File. Effective analysis of certain types of EMC problems requires the availability of digitized topographic data, that is, topographic data in a digital data format for computer accessibility. This information is stored at ECAC on magnetic tapes in the form of rectangular arrays representing elevations recorded at spacings varying from approximately 100 to 3000 feet.

1.5.2 Data Base Services

a. Environmental File Summary Listings. Listings of environmental file data for the Continental United States (CONUS) and Alaska are updated and published approximately once a year. In addition, special listings can be provided for any area where ECAC has data. These can be provided either as computer printouts, on punched cards, or on magnetic tape.

b. Equipment Characteristics Summary Listings. Equipment characteristics listings are published periodically in multiple-volume directories. Listings of such information as military C-E equipment, military electronics (including navigational) equipment, and commercial C-E equipment are available. Magnetic tape copies and punch cards of this file can be provided upon request, on a need-to-know basis.

c. Special Computer Output Listings. In addition to the listings, there are other ways in which the environmental file data may be selected and sorted to provide special listings as to the amount, type, and order of information, and may also contain selectable file information beyond that contained in the standard listings.

1.5.3 Analytical Services

The availability of an extensive data base at ECAC and the development of expertise and specialized analysis techniques enable ECAC to provide a unique service in studying and investigating EMC problems.

a. The Center provides assistance primarily in system-to-environment and environment-to-system compatibility situations, with some capability for intersystem analysis.

NOTE

Intersystem compatibility for this purpose refers to interactions between several systems in a restricted area. System-to-environment and environment-to-system compatibility involves the mutual interactions between all users of the electromagnetic spectrum over large physical areas.

b. The following are examples of analyses provided by ECAC:

o Development of a list of equipments possibly causing interference to, or experiencing interference from, equipments proposed for development, acquisition, modification, and installation.

o Guidance to selecting locations for satellite communications system ground station terminals.

o Evaluations and implications of various advanced system design parameters on operational performance in the system's intended environment.

o Guidelines for making frequency assignments to various communications and radar mobile/tactical systems, and guidance for interference-free deployment and use.

o Determination of expected in-band and out-of-band performance characteristics of planned transmitters and receivers.

o Map overlays showing the power density contours in a geographic area containing one or more transmitters.

o Map overlays showing the areas in which an airplane cannot be detected by a ground-based radar because of shielding by topographic features.

o Spectrum occupancy displays (computer printouts) showing the number of C-E equipments assigned to specified frequency bands and channel increments. The information is obtained from the ECAC environmental data base.

c. Since each compatibility analysis task has its own special objectives and requirements, it is not practical to specify "Standard" outputs or formats which ECAC would provide as a result of a study. Outputs can range from narrative discussion of interference effects and possible remedial techniques, to tabulations of expected performance levels, to graphs and curves suitable for use in further analysis of the situation.

1.5.4 Procedures for Requesting Summary Listings

Documents such as C-E directories and environmental file listings are available at the National Technical Information Service, Department of Commerce, Springfield, Virginia 22151. Also available are ECAC publications relating to analytical techniques. When requesting these documents, the user will complete DDC Form 55 and send it through the necessary approval channels to ECAC. If approved by CNO (OP-941F/N64), ECAC, as the releasing agency, will certify and return the form to the user who, in turn, must submit the form according to established procedures.

1.5.5 Requests for ECAC Services

Requests for analytical services or data base information as outlined in OPNAVINST 2410.29, should be addressed through military channels to include CNO(OP-941F/N64) in the routing chain to:

Navy Deputy Director ECAC
North Severn, Annapolis, Maryland 21402

The following information should be included with the request:

o The agencies and organizations that will use the outputs.

o An explanation of the information desired with as much detail as possible.

o An indication of the application for which the information is desired.

o A complete and clear justification of the need to know, and authority for access to classified information.

CHAPTER 2

SYSTEM CONSIDERATIONS

2.1 SYSTEM VIEWPOINT

Although many specifications and standards exist which may be applied against individual electronic equipments for the purpose of interference control, these documents do not necessarily insure electromagnetic compatibility when a multiplicity of equipments are located in a common electromagnetic environment. Many cases have been recorded where a well-designed piece of equipment failed to perform its intended function because of electromagnetic incompatibility with another equipment at the intended location. A classic example is the case of the prime contractor who developed, at great expense to himself, a very sensitive, high-frequency communications receiver for a missile system. Special tubes had been developed, waveguides and antennas had been designed, and packaging configurations were complete. Unfortunately, this system was to be collocated with a doppler navigation radar working at exactly the same frequency. Design changes necessitated by a shift in frequency proved to be an expensive lesson. The application of interference control measures to individual equipment, without regard for those measures already applied at interfacing equipment, can also result in redundancy, with associated increased cost, weight, and design time.

The system design approach avoids these problems because system design for EMC/RADHAZ means approaching the problem at the very beginning of project activity, wherein a detailed functional design study is made of the overall system, its constituent subsystems and equipments, and the intended operational environment. At that time, the EMC/RADHAZ problem is defined, possible contributory factors are analyzed, and necessary goals are established. In general, the four desired goals in the achievement of optimum compatibility are:

o Minimization of electromagnetic emissions which may affect other equipment (effects of the system upon external elements - inter-system).

o Minimization of susceptibility to emissions (e.g., effects of external elements upon the system - inter-system).

o Minimization of emissions and susceptibility between equipments within a system (internal effects - intra-system).

o Elimination of potential radiation hazards to both personnel and materiel.

System designs also mean that EMC must be integrated into all project activities throughout the project life to assure the accomplishment of these goals from a preventive-measures approach rather than the use of inefficient, costly, after-the-fact remedies.

The implementation of EMC/RADHAZ, therefore, calls for the establishment, by both government and industry management, of a formal program having well-defined objectives and controls. Such a program is discussed in the following paragraphs.

2.2 EMC/RADHAZ PROGRAM OBJECTIVES

EMC programs and their objectives have been described in detail in the literature. A summary of the salient features follows.

The establishment of an EMC/RADHAZ program within the framework of an overall project must include a clear statement of the objectives of such a program. In general, a formal program will have the following objectives:

o Gathering of information and data, including spectrum signature measurement data on the equipment or system and on the intended operational electromagnetic environment.

o Selection, interpretation and application of EMC/RADHAZ specifications and standards, engineering methods, and testing procedures which may be applied toward the selection or design of equipments.

o Selection and application of methods of prediction of both interference and radiation hazards in the intended environment, based on information gathered.

o Dissemination of gathered information to all personnel concerned with the planning, design, or installation of the equipment or system.

o Generation of an EMC/RADHAZ program plan when required, which states the specific practices, procedures, design criteria, etc., to be used (and to be avoided) to achieve EMC/RADHAZ throughout all phases of a program. Details of such a plan are presented in Appendix A.

o Establishment of an EMC/RADHAZ educational program.

A well-conceived and executed EMC/RADHAZ program will preclude difficult after-the-fact field fixes or crises which may arise at the installation and checkout phases and which, while costly in terms of time and dollars, usually are not amenable to satisfactory solution. Cases have been recorded where entire systems had to be redesigned to meet the mission requirements. Since the EMC/RADHAZ program forms one facet of an overall project, the EMC/RADHAZ program plan will be integrated with and become a part of the main project plan, the Base Electronics System Engineering Plan (BESEP). The general requirements of the BESEP for systems compatibility and radiation hazards, as outlined in NAVELEXINST 11000 series, will thus be met.

2.3 EMC/RADHAZ FUNCTIONS

The EMC/RADHAZ program plan is the heart of the program and establishes the philosphy for the project. From it comes the detailed documentation for electromagnetic interference control, grounding, bonding, shielding, wiring and cable routing, suppression and filtering, and criteria for protection from EMR hazards. In addition, the plan outlines the approach to meet the EMC/RADHAZ requirements and the test program required to meet specified limits. The program plan is a dynamic document, changing as information from the EMC reviews is fed back, and as it receives updated information from the prediction function.

2.3.1 Input Functions

a. Environmental Data and Siting Criteria. The electromagnetic environment in which the equipments are to function should be defined by the field activity in order to achieve a realistic EMC/RADHAZ program plan. Attention should be paid to:

(1) Site survey for determination of ambient levels.

(2) Collocated systems/equipments.

(3) Possible sources of interference, such as power lines and industrial activity.

(4) Site layouts.

b. Specifications and Standards. Documents which may have been selected and incorporated for the specific system/equipments provided for installation include: MIL-STD-461 and MIL-STD-469 for equipments, MIL-E-6051 for systems, and other applicable documents. These are discussed further in Chapter 3.

c. Preliminary Design and Prediction Data. Preliminary design includes the gathering of technical data for planning purposes, defining of the overall system performance characteristics, including selection frequencies and waveshapes, and analysis of interference and RADHAZ possibilities, both within the system and contributed to the external environment by the system (Prediction Process). Technical data may be acquired from:

(1) Technical manuals

(2) Technical orders

(3) Handbooks and other publications

(4) Reports to military agencies for similar or identical equipments used in other systems

(5) ECAC

(6) Equipment qualification reports.

Information acquired or produced from gathered data should include:

(1) Co-channel and adjacent channel interference

(2) Harmonics

(3) Spurious radiation

(4) Equipment susceptibility

(5) Transients

(6) Circuit impedances and coupling

(7) Frequency responses

(8) Propagation data

(9) Potentially hazardous areas or conditions.

2.3.2 Test Plans

A test plan should be prepared to outline those tests required to demonstrate system compatibility and the presence of potential RADHAZ. It is a written plan which may include equipment tests, subsystem tests, and finally, tests at the system level. Techniques and measuring equipment to be employed may be based upon the pertinent military standards described in Chapter 3.

2.3.3 Engineering Functions

a. System Concepts.

b. Selection and interpretation of specifications and the gathering of technical data.

c. Analysis, prediction, and modelling.

d. Equipment considerations.

e. Equipment and system testing.

f. Packaging, bonding, grounding, shielding, and supression techniques.

2.3.4 Installation Functions

a. Location and orientation of equipments.

b. Equipment interfacing.

c. Cable routing, ground connections, bonding, and shielding implementation.

d. Equipment configuration (e.g., consoles, panels, etc.).

2.3.5 Hazards Functions

a. Prediction of potential hazards to personnel and materiel.

b. Site measurements of antenna patterns, power densities.

c. Implementation of protective measures as required, e.g., installation of radar fences, warning signs, interlocks, etc.

2.4 SUMMARY OF EMC/RADHAZ CONTROLS

In order to achieve the objective of compatible, hazard-free operation of equipment within an overall project program, controls must be applied at each of the major functional activities.

2.4.1 Management Controls

a. Establishment of a group or individuals responsible for EMC/RADHAZ program within the project team.

b. Preparation of formal program plan.

c. Designation of applicable documents.

d. Designation of authority in all EMC/RADHAZ matters.

e. Analysis of skills and abilities required for each project phase.

f. Documentation and dissemination of all activities accumulated and generated data.

g. Design and test review, with approvals, at each project phase.

h. Establishment of training programs for the various job categories involved in the project.

i. Integrate data into the ECAC and other data centers to receive, compile, and analyze.

j. Prepare significant summaries of EMC/RADHAZ data, such as EMC/RADHAZ trends, spectrum signatures, and possible troublesome areas.

k. Provide for interchange of pertinent information with government agencies.

2.4.2 Design and Engineering Controls

a. Requirements

(1) Establish system requirements.

(2) Provide information on operational compatibility, mission and time compatibility, and minimum acceptable degradation for the mission, when requested.

(3) Perform spectrum studies to evaluate the validity of frequency assignments and submit recommendations.

(4) Develop alternate methods to perform the same function.

(5) Develop the necessary information studies and guidelines for achieving compatibility and stability.

(6) Perform tradeoff studies.

(7) Translate EMC/RADHAZ requirements into optimum installation.

(8) Prepare installation specifications for contractors.

(9) Prepare lists of equipments to be installed with their equipment characteristics.

(10) Promulgate and maintain environmental criteria on handling, storage, ground operations, and the definitions of environmental test limits.

b. Analyses

(1) Conduct analyses to determine criticality, system identification of potential interference, susceptibility, and hazards.

(2) Analyze operating procedures and instructions to ensure that interference and susceptibility modes are not introduced.

c. Controls for Improvement Studies

(1) Initiate and prepare recommendations for improvement when information indicates the allocated requirements will not be attained.

(2) Conduct improvement studies to predict the compatibility of potential interference, susceptibility modes, and potential hazards.

(3) Provide results of EMC/RADHAZ studies for use in other programs/projects.

2.4.3 Prediction and Testing Controls

a. Observe out-of-tolerance effects of potential emission generators.

b. Provide information that would allow logical test procedures.

c. Formulate an EMC/RADHAZ test plan.

d. Evaluate prototype demonstration tests.

e. Use test results to determine EMC and presence of EMR hazards.

2.4.4 Installation Controls

a. Utilize established siting criteria for equipment installation.

b. Provide rules for grounding, bonding, shielding, cable runs, and equipment mounting and interfacing.

c. Use manuals, technical orders, etc., which fully describe the proper methods and procedures for setting up, checking, adjusting, aligning, calibrating, and operating the equipment.

d. Inspect and approve installation to assure that the desired emission, susceptibility, and hazard modes are not introduced.

2.4.5 Hazard Controls

a. Apply RADHAZ prediction methods.

b. Apply appropriate protective methods for personnel and materiel.

c. Implement medical surveillance program, as required.

d. Conduct measurements of field patterns and power densities at the intended environment.

2.4.6 System Test and Operation Practices and Standards

a. Make available field manuals and technical orders which fully describe the proper methods and procedures for setting up, checking, adjusting, aligning, calibrating, and operating equipment prior to test or operational use.

b. Implement policies and procedures to ensure adherence to prescribed safety measures for the repair and maintenance of equipment.

c. Apply testing procedures to determine equipment/system performance degradation from storage or use.

CHAPTER 3

SPECIFICATIONS, STANDARDS, AND DOCUMENTS

3.1 EMISSIONS AND SUSCEPTIBILITY

Since the issuance of MIL-I-6181 in 1950 many EMC/EMI specifications have appeared, most of them outgrowths of MIL-I-6181 adapted or modified to fit a specific service requirement. Each of the military services has issued different standards and specifications covering emission and susceptibility characteristics, measurements, and requirements for systems and equipments. Because of the problems created by the numerous documents and their interpretation, the Department of Defense initiated a program for the consolidation of documentation in the EMC field. The outgrowth of this effort was the issuance of the DOD documents MIL-STD-461, 462, and 463 providing for the standardization and simplification of EMI requirements for equipments. This three-part document supersedes many of the older specifications in common use, e.g., MIL-I-6181, MIL-I-16910, MIL-STD-826 and others. Table 3-1 is a listing of latest issue military and commercial EMC/RADHAZ specifications, standards, and documents. Superseded documents have been listed because many of these "earlier" documents, while in the process of being phased out, are still encountered. So long as technology provides improved procedures, and as electronic systems and equipment grow in complexity and density, it is certain that continual revision of these specifications will be mandatory.

To have meaningful use, standards and specifications should be applied at the inception of a project. Selection and tailoring of the requirements in applicable specifications and standards for the project should occur at this phase.

3.2 DOCUMENT SYNOPSES

The more comprehensive of those listed documents in Table 3-1 are MIL-STD-449, 461, 462, 463, 469, 1310, and Military Specification MIL-E-6051; a brief description of each follows.

o MIL-E-6051, Electrical-Electronic System Compatibility and Interference Control Requirements for Aeronautical Weapon Systems, Associated Subsystems and Aircraft. Of all the listed documents, MIL-E-6051 is the only one to approach the EMC problem from a systems viewpoint, i.e., it requires total system compatibility, including test, checkout, and support equipment where such equipment is capable of contributing to the electromagnetic environment. No specific test procedures or equipment are outlined. Instead, MIL-E-6051 requires the preparation by the contractor of a detailed test plan wherein it is demonstrated that all elements of a system operate properly, both individually and collectively, and that there is at least a 6 dB margin between the susceptibility level of each equipment and the electromagnetic interference environment resulting from the operation of the total system.

o MIL-STD-449, Measurement of Radio Frequency Spectrum Characteristics, is a DOD document established to provide standard techniques for the measurement of radio-frequency spectrum characteristics of electronic equipment. The data obtained may be used to predict equipment and systems performance in an operational electromagnetic environment, predict the effect of a particular equipment or systems on the electromagnetic environment of other equipment or systems, to establish the characteristics required of new equipment for compatible operation in present and future environments. The document sets forth specific requirements such as accuracy of frequency measurements, number of points for antenna pattern data, dynamic range of measurements, standard test frequencies, and format for data. The emission and susceptibility characteristics of

transmitters and receivers obtained by use of MIL-STD-449 are maintained in a Spectrum Signatures Library by the DOD Electromagnetic Compatibility Analysis Center and are available for use by all naval activities involved in EMC problems, as discussed earlier in paragraph 1.5.

o MIL-STD-469, Radar Engineering Design Requirements, Electromagnetic Compatibility, represents an initial attempt by the military departments to control the spectral characteristics of new radar systems by establishing minimum engineering design criteria. The document specifies limits and tolerances for frequencies, emission and acceptance bandwidths, spurious radiation, stability and other parameters. It also specifies test procedures and instrumentation for obtaining these parameters.

o MIL-STD-1310, Shipboard Bonding and Grounding Methods for Electromagnetic Compatibility, outlines equipment installation requirements, and shipboard construction and bonding methods for the minimization of EMI aboard Naval Ships and Submarines. Particular emphasis is placed on bonding and grounding techniques to ensure, as nearly as possible, that the topside area be made a single RF conducting structure.

o MIL-STD-461, Electromagnetic Interference Characteristics Requirements for Equipments, MIL-STD-462, Electromagnetic Interference Characteristics, Measurement of, and MIL-STD-463, Definitions and Systems of Units, Electromagnetic Interference Technology. These three standards taken together form a coordinated document which establishes requirements, test limits and techniques for the measurement of the EMI characteristics of electronic, electrical, and electromechanical equipment. The requirements are set forth to ensure that interference control is considered and incorporated into the design of equipment, and that compatible operation of the equipment in a complex electromagnetic environment is achieved. A number of tests, covering both conducted and radiated, emission and susceptibility characteristics are outlined, making these documents the most comprehensive of the interference standards. The equipment class, use, and intended installation as defined in MIL-STD-461, determines which of the MIL-STD-462 tests are applicable.

Table 3-1. EMC/RADHAZ Specifications, Standards, And Documents

SPECIFICATIONS	TITLE	DATE	AGENCY
AFSC DH 1-4	Electromagnetic Compatibility	Current issue	USAF
AFSCM 100-31	Frequency Management and Electromagnetic Compatibility	13 March 1970	USAF
ANSI STD C63.2	American Standard Specifications for Radio Noise and Field Strength Meters 0.015 to 30 MHz	28 March 1963	ANSI
ANSI STD C63.4	Methods of Measurement of Radio-Noise Voltage and Radio-Noise Field Strength, 0.015 to 25 MHz, Low Voltage Electric Equipment, and Nonelectric Equipment	1963	ANSI
BSD Exhibit 67-87	Electro-interference Control Requirements for Minuteman (WS-133B)	12 June 1962	USAF, BSD Note (5)
D65/9371	General Requirements for Electrical Equipment and Indicating Instruments for Aircraft; RFI		British Standards Institute
DO 138	Environmental Conditions and Test Procedures for Airborne Electronic/Electrical Equipment and Instruments		RTCA Note (6)
FCC Part 15	Rules and Regulations, Radio Frequency Devices	May 1966	FCC
FCC Part 18	Rules and Regulations, Industrial Scientific, and Medical Equipment	May 1966	FCC
JAN-I-225 Note (4)	Radio Interference Control and Test Requirements	14 June 1945	USAF
MIL-B-5087	Electrical Bonding and Lightning Protection for Aerospace Systems	16 Oct. 1964	USN, USAF
MIL-C-11693	General Specification for Radio Frequency Interference Reduction Capacitor, AC and DC, Hermetically Sealed in Metal Cases	8 Feb. 1962	USA, USN, USAF
MIL-E-4957 Note (4)	Electromagnetic Shielding Demountable Enclosure, Prefabricated for Electronic Test Purposes	17 Nov. 1954	USN, USAF
MIL-E-6051	Electrical-Electronic System Compatibility and Interference Control Requirements for Aeronautical Weapon Systems, Associated Subsystems and Aircraft	7 Sept. 1967	USA, USN, USAF
MIL-E-55301 (EL) Note (1)	Electromagnetic Compatibility	1 March 1966	USA

Table 3-1. EMC/RADHAZ Specifications, Standards, And Documents (Con't).

SPECIFICATIONS	TITLE	DATE	AGENCY
MIL-F-15733	Radio Interference Filters	15 Aug. 1966	USA, USN, USAF
MIL-F-18327	General Specification for Filters; High Pass, Low Pass, Band Pass, Band Suppression and Dual Functioning	25 May 1966	USA, USN, USAF
MIL-F-25880	Band Pass, Band Suppression Filter	29 Jan. 1960	USAF
MIL-I-6181 Note (1)	Aircraft Equipment Interference Control Requirements	1 June 1962	USA, USN, USAF
MIL-I-11683 Note (2)	Requirements for Engine Generators and Miscellaneous Engines Radio Interference Suppression	19 Jan. 1953	USA, USN, USAF
MIL-I-11748 Note (2)	Interference Reduction for Electrical and Electronic Equipment	4 Nov. 1958	USA
MIL-I-16165	Engine Electrical Systems Interference	12 Aug. 1961	USN
MIL-I-16910 Note (1)	Electromagnetic Interference Measurement, Methods and Limits	26 Oct. 1964	USN
MIL-I-17623 Note (1)	Electromagnetic Interference Measurement Methods and Limits, for Electric Office Machines, Printing and Lithographic Equipment	19 April 1965	USN
MIL-I-26600 Note(3)	Interference Control Requirements Aeronautical Equipment	9 May 1960	USAF
MIL-I-43121 Note (1)	Interference Reduction for Electric Hand Tools	30 Aug. 1965	USA, USN, USAF
MIL-P-24014	Preclusion of Hazards from Electromagnetic Radiation to Ordnance, General Requirements for	30 Jan. 1965	USN
MIL-R-9673	Radiation Limits, Microwave and X-Radiation Generated by Ground Electronic Equipment (As Related to Personnel Safety)	13 Feb. 1961	USAF
MIL-S-10379 Note (1)	General Requirements for Vehicles and Vehicular Subassembly Radio Interference Suppression	23 July 1952	USA, USN, USAF
MIL-S-12348 Note (1)	General Requirement, Radio Interference Suppression	6 Aug. 1958	USA, USN, USAF

Table 3-1. EMC/RADHAZ Specifications, Standards, And Documents (Con't).

SPECIFICATIONS	TITLE	DATE	AGENCY
MIL-S-13237 Note (2)	Radio Interference Suppression Requirements for Watercraft		USA
MIL-S-13715	Transients on Vehicles		USA
MIL-STD-220	Method of Insertion-Loss Measurement	15 Dec. 1959	USA, USN, USAF
MIL-STD-285	Method of Attenuation Measurements for Electromagnetic Shielding Enclosures for Electronic Test Purposes	25 June 1956	USA, USN, USAF
MIL-STD-449	Measurement of Radio Frequency Spectrum Characteristics	1 March 1965	USA, USN, USAF
MIL-STD-461	Electromagnetic Interference Characteristics Requirements for Equipment	1 Aug. 1968	USA, USN, USAF
MIL-STD-462	Measurement of Electromagnetic Interference Characteristics	31 July 1967	USA, USN, USAF
MIL-STD-463	Definition and System of Units, Electromagnetic Interference Technology	9 June 1966	USA, USN, USAF
MIL-STD-469	Radar Engineering Design Requirements Electromagnetic Compatibility	1 Dec. 1966	USA, USN, USAF
MIL-STD-826 Note (1)	Electromagnetic Interference Test Requirements and Test Methods	30 June 1966	USAF
MIL-STD-833	Minimization of Hazards of Electromagnetic Radiation to Electroexplosive Devices	31 July 1963	USAF
MIL-STD-1310	Shipboard Bonding and Grounding Methods for EMC	27 Dec. 1967	USN
MOL 64-4	General EMC Specification for Systems	April 1965	USAF
MSC, Houston IESD-19-3	Interference Control Requirements for Spacecraft Equipment		NASA
MSC, Houston PACE-S/C, Project Office Spec. 53, Rev 1 to MIL-I-26600	Performance Specification for Equipment Grounding Requirements on Preflight Acceptance Checkout Equipment Spacecraft (PACE S/C) Program		NASA
MSFC-SPEC-279	Electromagnetic Compatibility	1 June 1964	NASA

Table 3-1. EMC/RADHAZ Specifications, Standards, And Documents (Con't).

SPECIFICATIONS	TITLE	DATE	AGENCY
NAVFAC 50-YA Note (1)	Overhead Power Lines Operating at Voltages from Zero to 1000 kV, 14 kHz to 1 GHz	April 1966	USN
NAVMAT P-5100	Safety Precautions for Shore Activities	March 1970	USN
NAVMED P-5052-35	Control of Hazards to Health From Laser Radiation	24 Feb. 1969	USN
NAVMED P-5055	Radiation Health Protection Manual	6 Nov. 1968	USN
NAVORD OP 3565/ NAVAIR 16-1-529	Technical Manual - Radio Frequency Hazards to Ordnance, Personnel, and Fuels		USN
NAVSHIPS 0900-005-8000	Technical Manual for Radio-Frequency Radiation Hazards	15 July 1966	USN
SAE-J551	Measurement of Vehicle Radio Interference (30-400 MHz)		SAE Note (7)
SAE ARP-936	10 Microfarad Capacitor for EMI Measurements		SAE
SAE ARP-958	Measurement of Antenna Factors		SAE
STANAG 3516	EMC Test Methods for Aerospace Electrical and Electronic Equipment		NATO
T.O. 31Z-10-4	Electromagnetic Radiation Hazards	10 May 1967	USAF

Notes:

(1) Superseded by MIL-STD-461/462, inactive for new designs
(2) Superseded by MIL-E-55301 (EL)
(3) Superseded by MIL-STD-826
(4) Cancelled
(5) USAF Ballistic Systems Division
(6) Radio Technical Committee for Aeronautics
(7) Society of Automotive Engineers

CHAPTER 4

UTILIZATION OF THE FREQUENCY SPECTRUM

4.1 BACKGROUND

The rapid growth in the quantity and complexity of communication-electronics equipments and the increased international requirements for radio frequencies have placed unprecedented demands upon the radio frequency spectrum. These demands include such service applications as communications (fixed, mobile, broadcast, space); location and ranging (radar, beacons, radionavigation); identification; standard time and frequency transmissions; and industrial, medical, and other scientific uses.

The usable radio frequency spectrum, however, is a limited resource, recognized by international treaty. The Space World Administrative Radio Conference (WARC) convenes periodically to consider allocation of the spectrum. Portions of the spectrum are already critically congested, making it extremely difficult to obtain new frequencies or to increase bandwidth on presently assigned frequencies. To satisfy the demands on the spectrum in an orderly manner, a frequency management function is necessary, which incorporates solid engineering and administrative practices towards control of the spectrum supply and demand.

4.2 FREQUENCY MANAGEMENT ORGANIZATION AND RESPONSIBILITIES

Frequency management may be defined as the function whereby:

o Requirements for use of the radio frequency spectrum are presented, reviewed, and satisfied; initially, and on a continuing basis.

o Control of the use of the spectrum is exercised. The primary objective of frequency management is the satisfaction of all frequency requirements without causing degradation to communication-electronics service. Another important objective is the conservation of the radio spectrum. The organization and responsibilities of the various existing frequency management levels are described in detail in DNC-15(A), "U.S. Navy Frequency Management Handbook." Descriptions of these levels follow.

4.3 INTERNATIONAL FREQUENCY MANAGEMENT

The International Telecommunications Union (ITU) is an international body wherein the nations of the world cooperate toward improved and effective use of telecommunications and the radio frequency spectrum resource. Created in 1865, as the International Telegraph Union with 20 member nations, the ITU is now an organ of the United Nations. The major material output of the ITU results from the joint efforts of the member nations, usually in the form of Radio Regulations which have treaty status and thus, upon adoption by a country, become the law of the land. ITU headquarters are in Geneva, Switzerland, where a permanent secretariat is supported by member nations.

The ITU establishes and promulgates the international allocation of, and regulations for the use of, the radio frequency spectrum. It also promotes the development of technical facilities and establishes doctrine for international telecommunications, including the aforementioned Radio Regulations. The ITU Secretariat serves as a focal point for disseminating to all member nations such information as stations, call signs, radio service

schedules, and recommended technical standards and tolerances. An international monitoring effort is also maintained under ITU auspices for the purpose of determining spectrum occupancy.

There are several international technical bodies within the ITU. They strengthen and support the parent organization and contribute directly to improved telecommunications by such means as technical papers and recommended standards.

4.3.1 Basic Rules for Assignment and Use of Frequencies

a. ITU member nations have agreed that, in assigning frequencies to stations capable of causing harmful interference to the services rendered by stations of another nation, such assignments must be made in accordance with the Table of Frequency Allocations and other provisions of the Radio Regulations.

b. Any new or revised assignment shall be made in such a way as to avoid causing harmful interference to services rendered by assignments made in accordance with the Table of Frequency Allocations and recorded in the Master International Frequency Register.

c. The frequency assigned to a station of a given service shall be separated from the limits of the band allocated to this service in such a way that, taking into account the bandwidth assigned, no harmful interference is caused to services to which frequency bands immediately adjoining are allocated.

d. Where a band of frequencies is allocated to different radio services in adjacent geographic regions, the basic principle is the equality of right to operate. Accordingly, the stations of each service in one region or sub-region must operate so as not to cause harmful interference to services in the other regions or sub-regions.

4.4 NATIONAL FREQUENCY MANAGEMENT

The basis for U.S. National Frequency Management is derived principally from the Communications Act of 1934, as amended. This Act provides for a bilateral arrangement; the Federal Communications Commission (FCC) is responsible to the Congress for the regulation of United States non-government activities; the President is responsible for the operations of federal government agencies consisting of the following:

o The President, by Executive Order, has delegated the task and authority for assignment and control of radio frequency resources used by government agencies to the Office of Telecommunications Policy (OTP) under the Executive Office of the President. The OTP is responsible for formulating policies and standards pertaining to the operation of telecommunications systems by government activities, subject to the authority and control of the President.

o The Interdepartment Radio Advisory Committee (IRAC), established in 1922, and composed of frequency management representatives of principal government agencies engaged in use of the frequency spectrum, serves in advisory capacity to the OTP. The Departments of the Army, Air Force, and Navy each has representation on the IRAC.

o Functions of the Interdepartment Radio Advisory Committee, acting for the OTP, are to approve, in collaboration with the FCC, the allocation of frequency bands to radio services in the United States and Possessions (US&P) within the provisions of the international allocation table, to authorize the assignment of frequencies to government radio stations, to assist and advise appropriate national authorities on related technical problems, and to serve as an advisory body to the Department of State in the formation of U.S. positions for international conferences.

o The actual assignment authority for the radio frequency use by the U.S. government agencies is vested in the Frequency Assignment Subcommittee (FAS) of the IRAC, which is composed of the representatives of the following government agencies with liaison representation from the FCC:

Department of Agriculture
Department of the Air Force
Department of the Army
Department of Commerce
Federal Aviation Agency
Department of Interior
Department of Justice
National Aeronautics and Space Administration
Department of the Navy
Department of Transportation
Department of Treasury
United States Postal Service
United States Information Agency
Veterans Administration
Atomic Energy Commission
National Communications System

o Among government agencies not participating in the FAS, but served by it are: Department of Health, Education, and Welfare; Tennessee Valley Authority; and the Federal Reserve System.

o Prior to use of any radio frequency within the US&P, except certain military low power tactical and training operations, and ECM operations which do not fall within a restricted frequency band, U.S. government agencies are required to obtain authorization in the FAS for the specific frequency and parameters of use. The procedure for coordination and use of certain non-government allocated frequencies for military tactical and training purposes is set forth in the OPNAVINST 2410.19 series, and JANAP 195.

o Listings of all assignments approved for government agencies by the FAS are contained in the volumes of the "Frequency Assignments to Government Radio Stations," commonly known as the "IRAC Station List." The list for which revisions are regularly printed, is promulgated by the IRAC on behalf of the OTP. The IRAC also publishes the U.S. National Table of Frequency Allocations. This table amplifies the ITU allocations in the form of subdivisions of basic radio services plus delineation as to whether government and/or non-government operations are authorized in each allocation.

4.4.1 Department of Defense Frequency Management

The Department of Defense, as an entity under the Secretary of Defense (as well as the three military departments individually) is an integral component of the U.S. National Frequency Spectrum Management structure.

The prime focal points, however, are the principals of the communications-electronics staffs of the military departments who respond through the Joint Staff or intradepartmental chain according to the joint or intradepartmental nature of a matter under consideration. The flow of authority on frequency matters may be multilateral through the Secretary of Defense. Coordination on a single Navy frequency problem may go through both chains. Policy and assignment of responsibilities within the Department of Defense are established by DOD Directive 4650.1 series, "Management and Use of the Radio Frequency Spectrum."

Levels of Department of Defense frequency management responsibility are briefly described in the remainder of this chapter.

a. Military Communications-Electronics Board (MCEB)

(1) The mission of the MCEB is to:

o Achieve coordination on military communications-electronics matters among DOD components, by the DOD and other governmental departments and agencies, and between DOD and representative of foreign nations.

o Provide DOD guidance and direction in those functional areas of military communications-electronics for which the MCEB is assigned responsibility.

o Furnish advice and assistance, as requested, on military communications-electronics matters to the Secretary of Defense, the Joint Chiefs of Staff, the military departments and other DOD components.

(2) The MCEB is composed of:

o The Director, Defense Communications Agency (DCA), chairman

o The Chief, Communications-Electronics, U.S. Army

o The Director, Naval Communications (COMNAVCOMM)

o The Director of Command, Control and Communications, U.S. Air Force

o The Chief, Communications-Electronics, U.S. Marine Corps

o The Director for Communications-Electronics (J6), Joint Staff

o A representative of the Director, National Security Agency

b. Joint Frequency Panel (JFP). The Joint Frequency Panel is responsible to the Military Communications-Electronics Board in the accomplishment of its mission in the areas of radio propagation and frequency allocation, coordination and assignment. The JFP consists of a minimum of one member and an alternate from each service or Agency within the composition of the MCEB who has an interest in the activities of the Panel plus one representative and an alternate from the U.S. Coast Guard. The present membership consists of Army, Navy, Air Force, Joint Staff (J6), USMC, Coast Guard, DCA, and NSA.

The mission of the JFP is to:

(1) Review, develop, and coordinate studies.

(2) Report DOD positions and recommendations for the MCEB on frequency management and engineering, radio wave propagation, and electromagnetic compatibility (EMC).

(3) Implement for MCEB the provisions of DOD Directive 4650.1, "Management and Use of the Radio Frequency Spectrum."

(4) Coordinate frequencies to meet joint, national, and allied requirements.

(5) Coordinate and assign frequencies to meet U.S. military requirements (other than those of an individual service nature).

(6) Coordinate and assign unified command frequencies.

c. Unified and Specified Commands. The commanders, under the Joint Chiefs of Staff have overall management and control responsibility of all U.S. military use of radio frequencies within their zones of operations; this has significant impact upon the Navy frequency planning form for worldwide fleet and shore establishment operations.

The JFP coordinates with a Commander in Chief (CINC) all JFP frequency assignments made to that CINC's area of jurisdiction. Under certain conditions (U.S. Supp. 1A, ACP*190), the unified commander can assign frequencies for low powered local operations (under 500 watts) without reference to the JFP. All assignments (including those under 500 watts) within U.S. possessions must have IRAC approval. The unified commander submits to the JFP all frequency requirements for low power operation for which no authority exists in the IRAC publication.

d. Defense Communications Agency (DCA). The DCA was established in 1961 with the mission of ensuring that the Defense Communications System (DCS) would be so established, improved, and operated as to meet the long-haul, point-to-point, requirements of the Department of Defense and other associated government agencies as directed. The DCA is a management agency with no operational functions as such. The system with which they are concerned is basically the network of long-haul, point-to-point circuits operated by Army, Navy and Air Force communications organizations. Certain responsibilities are also assigned to DCA in connection with satellite communications. The Director of the DCA is selected by the Secretary of Defense.

The agency consists of a headquarters staff in Washington, D.C. and such other worldwide facilities as the Director, DCA feels justified for accomplishing the assigned mission. Staffing is effected from military personnel of the different departments, in accordance with directed demands upon the departments to support the DCS. The Director, DCA,is the Chairman of the MCEB. Detailed amplification of DCS definitions for the purpose of their mission is contained in DOD Directive 5205 series.

e. Area Frequency Coordinators (AFC). An inter-service area frequency coordination system was established by the JFP to ensure minimum interference to the C-E systems employed and tested on the national ranges. Specified areas of geographical cognizance are given in DNC-15(A). Frequencies intended for use in these areas are coordinated with the applicable AFC before assignment. The JFP has assigned the following responsibilities to the AFC (nothing in these functions is intended to usurp services' or commanders' prerogatives or responsibilities in frequency management):

o AFC s review and evaluate assignment requests proposed for use within their area. The review and evaluation establishes the compatibility of proposed frequencies with test range operations and other activities in the area. Requests in the Continental United States are forwarded to the departmental headquarters of the requesting military activity with supporting technical comment.

o AFC s assist, when requested, in the elimination of real-time harmful interference to in-being ranges and test site operations. In performing this function, the AFC s are authorized to request temporary radio silence, on a frequency or band of frequencies, of the interfering activity for the period of time necessary to complete operations in progress.

o AFC s may arrange, by mutual agreement among military activities within their geographical area, for time sharing and technical adjustments (emission, power output, etc.) on frequency assignments, as required, to minimize harmful interference.

* Allied Communication Publication

o AFC s maintain records of frequencies which have been coordinated and assigned for use in their areas. These records include frequencies assigned to military activities, military contractors, and those government and non-government assignments being shared with test range frequency assignments. Records of AFC s are made available to military activities for frequency planning.

4.4.2 U.S. Navy Frequency Management

Allocation for Navy Electronics Equipment. An office under the Chief of Naval Operations (CNO) has the responsibility for the Department of the Navy to secure joint approval of the frequency allocation provision for all Navy electronic equipments or systems purposely designed to emit or receive electromagnetic energy.

Such provision is effected prior to the development, procurement, or adoption of such equipments or systems. Unlike frequency assignments, authority to approve frequency allocation is always at the level of the office of CNO. Furthermore, CNO does not respond to an originating Navy Command or other development activity's request for allocation without having first secured joint approval, be it an experimental, developmental, or operational frequency allocation.

a. The Commander, Naval Communications (COMNAVCOMM) obtains authority for the use of radio frequencies within US&P in the following instances:

o For USN/USMC Communication-Electronics (C-E) operations which are physically located on board USN/USMC installations.

o For USN/USMC C-E operations on installations of other military departments.

o For C-E operations required to support jointly operated (e.g. USN/FAA) facilities on board USN/USMC installations.

o For the ECM type equipments which fall within restricted bands, OPNAVINST 3430.9 series pertains.

b. COMNAVCOMM does not normally obtain authority for the following type of operations:

o Facilities of military and nonmilitary agency tenant activities aboard a USN/USMC shore based installation not jointly operated with those agencies.

o Temporary operations by elements of other agencies on board USN/USMC shore based installations where those agencies have adequate frequency authorization.

The importance of the allocation provision process in the sequence of furnishing systems to the Fleet is supported by the policy of the Chief of Naval Material (CNM) which serves as a checkpoint in preventing expenditures for electronic equipments which lack required radio frequency allocation. This guidance to potential Navy procurement activities is set forth in NAVMAT Instruction 10550.11 series.

In order to be better prepared for consideration of spectrum allocation policy and engineering matters, the cognizant office of CNO reviews operation requirements papers generated within the Navy; continues such reviews through the development of Specific Operational Requirements (SOR s), Technical Development Plans (TDP s), which inform planning and material offices of any adverse elements noted; and makes such recommendations as are deemed appropriate from a frequency standpoint. Difficult or controversial items are studied and resolved by the Frequency Allocation Advisory Board (FAAB), the principal frequency coordinating body within the Navy.

In order to evaluate effectively the compatibility aspects of electronic equipments under conditions of anticipated operational employment as well as to conform to the national structure of frequency management, an orderly procedure for the processing of frequency allocation applications is necessary. Each military department is responsible for processing information to the JFP, a component of the MCEB, and for enforcement of resultant decisions. The procedure is promulgated within the Navy Department in OPNAVINST 2410.11 series, NAVMATINST 10550.11 series, and NAVELEXINST 2400.1. In those instances where research and development efforts are conducted under contract by private industry, it is the responsibility of the cognizant Navy SYSCOM to maintain sufficiently detailed surveillance of such activities to ensure that applications for experimental or developmental equipments are treated in advance of those submitted for production equipment programmed for operational use.

Applications are submitted to CNO in accordance with the instructions noted previously. Applications for frequency allocation are studied by CNO in the light of existing Joint Military electronic equipments, established design objectives, and the probable impact from and upon new equipment under development. The effective editions of JANAP 141 (U.S. Joint Military Radio Frequency Allocation Plan) and the Frequency Allocation List, U.S. Military Electronic Equipment are pertinent. Appropriate equipments are also considered for their impact on the combined environment by a Canadian-United Kingdom-United States working group of the Combined Frequency Panel.

Frequency allocation provisions are prescribed for each equipment on the assumption that production for operational (or for research and testing) use will materialize. CNO provides the Chief of Naval Material with copies of all completed frequency allocation actions, whether approved or disapproved, including conditions and modificaton recommendations.

4.4.3 Frequency Assignments

Even though a frequency band may be allocated to a service by international and national agreements, and an allocation has been approved for a specific transmitter on a Navy installation, specific authority in the form of an ASSIGNMENT is a prerequisite for use of the RF spectrum.

When it becomes necessary for a Navy command to set up a radio frequency transmission (other than in connection with Fleet Tactical Plans) at a specific location or for a purpose not already authorized, or in expansion of the frequency provisions of an already authorized operation, specific authority must be obtained from the Chief of Naval Operations or the Unified Commander, as appropriate. In turn, intramilitary, national, and international coordination will be effected, as necessary.

The first element of this process is validation of the requirements. Various steps in clearance coordination follow, culminating in the assignment. Frequency management action is concluded with entry into pertinent records. Monitoring of assignments to ensure continued need and usage is a never ending, follow up action.

COMNAVCOMM assigns all radio frequencies for use by USN/USMC activities within the US&P. In certain frequency bands COMNAVCOMM has assigned radio frequencies to Fleet Commanders in Chief and Naval District Commandants for further assignments. These assignments are covered in the various chapters of JANAP 195.

o The Fleet Commanders in Chief and Naval District Commandants are authorized to further assign specific operating frequencies, as appropriate, in those cases where the CNO has assigned frequency bands or complements of frequencies to the Fleet Commanders in Chief or Naval District Commandants.

o Fleet Commanders in Chief and Naval District Commandants maintain a current record of specific assigned frequencies in accordance with the previous paragraph.

o Naval District Commandants report to COMNAVCOMM all permanent frequency assignments made by the Commandant under broad COMNAVCOMM authority (less tactical and training assignments made pursuant to OPNAVINST 2410.19) in the bands 30-42 MHz, 138.0-150.8 MHz, 225-400 MHz. This information is required to determine and maintain records of U.S. Navy utilization of the radio frequency spectrum and is used for planning purposes at the national level.

In cases where COMNAVCOMM has assigned frequencies to the Fleet Commanders in Chief or Naval District Commandants for use by activities or installations under their cognizance, temporary variations in the assigned utilization of such frequencies may be authorized by the Fleet Commanders in Chief or Naval District Commandants as long as the remainder of COMNAVCOMM assignment parameters are observed.

Within the area of responsibility of a Unified Commander, frequency assignments are made by the Unified Commander in coordination with the Joint Frequency Panel of the USMCEB on behalf of the Joint Chiefs of Staff, as appropriate.

No radio frequency below 30 MHz is assigned to point-to-point (fixed circuits located within CONUS), except in one or more of the following instances:

o When security factors dictate paralleling wire circuits with radio circuits in essential communication channels of a command network (standby stations).

o When the radio circuit is for the domestic haul of overseas traffic, and is a relay segment of that overall system.

o When the use of other means of communication is impractical. Neither budget, personnel, nor convenience should be considered factors to justify satisfying a domestic point-to-point requirement for use of radio.

Active ECM Operations. Frequency authorizations for active Electronic Countermeasures (ECM) operations in the United States and Canada are established for U.S. Military units on a standing basis for certain bands, to be satisfied for each individual operation through local coordination. Authority, restrictions by band, and detailed coordination procedures are contained in a Joint Directive promulgated within the Navy Department under OPNAVINST 3430.9 series.

Operation of Naval Radar Equipment. Assignments for operation of Navy and Marine Corps radars are for the most part less specific as to center frequency in CNO and/or JFP authorization than in the case of other types of equipment. For this reason, greater attention must be given to operational directives and local coordination by operating force and shore based commanders. Assignments are authorized on a band or tuning limits basis to Fleet Commanders and District Commandants. Adjustment of tunable equipments for operation are then as set forth in JANAP 195. Within CONUS, frequency plans for fixed installations, as well as mobile units within the jurisdictional area, are the responsibility of the Naval District Commandant. Policy and procedures governing employment of IFF in conjunction with radar is set forth in JANAP 195 and OPNAVINST 2380.1 series. When a location is encompassed by the jurisdiction of a Test Range Area Frequency Coordinator, coordination with such office is also necessary. Operations in a theater under the control of a U.S. Unified or Specified Commander are subject to such additional instructions as may be issued to minimize interference in the theater, especially as regards operations within interference range of foreign countries where radar or other allocations may differ from U.S. allocations or uses.

4.4.4 Requests for Frequencies

Prior to the operation of any device intentionally radiating electromagnetic waves, a radio frequency authorization is obtained from competent authority.

Requests for the assignment of radio frequencies are normally submitted as follows:

o Requests for frequencies by shore activities for use within CONUS are submitted to the COMNAVCOMM via the Naval District Commandant and additionally, in the case of Naval tenant activities, via the base or installation commanders concerned.

o Requests for frequencies in the area of responsibility of a Unified/Specified Commander are submitted via the chain of command to the Unified/Specified Commander.

o Fleet units based ashore requiring radio frequencies for use at shore installations request frequencies from the cognizant Naval District Commandant.

o Requests for frequencies to be used by Naval Communications Stations are submitted to the COMNAVCOMM via the appropriate Fleet Commander in Chief.

Requests for frequencies to meet routine, foreseeable requirements should be received by the COMNAVCOMM in the format prescribed in Allied Communication Publication (ACP) 190 U.S. Supplement 1, "Basic Armed Forces (U.S.) Frequency Planning," at least sixty days prior to commencement of the requirement.

Requests for frequencies to be used within the area of cognizance of an Area Frequency Coordinator (AFC) or Sub-Area Frequency Coordinator (Sub-AFC), normally should receive comments from the appropriate AFC or Sub-AFC prior to receipt of the request by COMNAVCOMM or unified commander.

When a requirement exists for a shore based activity, within CONUS, to operate in local civil police, fire, or emergency nets, the request should list the specific frequency to be employed and should also include a letter of concurrence from the local civil agency involved.

When a requirement exists for a frequency assignment for a station located on any land or reservation under the jurisdiction of the Forest Service, Department of Agriculture or the Bureau of Land Management, Department of the Interior, the date of notification for permission to make the installation on the subject land or reservation, and the land office from which the notification was received, should be forwarded to COMNAVCOMM with the request for a frequency assignment.

USN/USMC activities with requirements for the use of 27.575 MHz or 27.585 MHz, in accordance with the provisions of JANAP 195, should submit requests for authorization to the appropriate Naval District Commandant.

Requests for renewal of frequency assignments made on a temporary basis should also be forwarded to reach COMNAVCOMM at least 60 days prior to the expiration of the temporary assignment.

4.4.5 Frequency Usage Program

A key part of Navy frequency management is the program of submission and employment of radio frequency usage reports. Details of action required by field activities in submission of reports are promulgated in the OPNAVINST 2400.7 series.

4.5 FREQUENCY SELECTION AND ENGINEERING

4.5.1 Planning Factors

The saturation of the limited radio frequency spectrum has been described. Maximum economy in the utilization of the spectrum is therefore essential in order that vital operations will not be degraded by inefficient distribution of this resource. The first duty of a requirements planner is to exhaust all possible combinations of power/emission and sharing of existing frequency assignments in meeting new requirements. Requests for routine, foreseeable frequency requirements must be submitted with sufficient lead time (60 days desired) so as to provide adequately for coordination at the Washington level as well as with major Area Frequency Coordinators (AFC's). Requests should normally include, in addition to specific frequencies desired and frequency limits if applicable, the following:

o Type of service

- o Points or areas of intended use
- o Maximum power and desired emissions
- o Equipment nomenclature
- o Hours of operation
- o Operations command.

a. This procedure is enumerated in JANAP 195. It is essential that initial requests be detailed adequately, clearly justified, and indicative of the results of any advance coordination effected by the originator. The latter might entail an FCC Field Engineer in Charge, FAA Regional Office, Military Test Range Area Frequency Coordinator (AFC), District Commandant Frequency Coordinator, etc. Advance local coordination, particularly at commands based overseas, may also include that informally effected with a foreign military liaison officer. The details necessary to decision making will vary with each individual situation. The originator should consider all echelons at which the matter will be treated in adjudging items of the standard format and provide extra amplifying facts as necessary to enhance the coordination process.

b. Communications circuit frequency assignment requests may be for augmentation of existing circuits or entirely new circuit paths, or may be for temporary periods for experimental work or tactical and training exercises. Advance direct coordination and subsequent "Viz" or "Copy to" inclusion in formal requests is dependent upon the chain of command plus other commands that are known to have frequency control responsibility or established radio services entailing potential mutual interference. The originator and each command commenting upon a proposal is responsible for adjudging that, if approved, the additional occupancy of the RF spectrum will not create harmful interference to established radio services. Additionally, justification of the requirement should be considered at each step in the chain of command processing.

c. Other significant planning factors

(1) Spectrum Limitation. Spectrum limitation is greatest in the HF portion (3-30 MHz) of the spectrum, especially during the low portion of the solar sunspot cycle. Practically all of the frequencies for point-to-point Defense Communications System circuits and for long-range tactical communications must be satisfied herein. To some extent, frequencies (1.7-3 MHz) in the MF band also serve such circuits depending upon terminal locations, time of day, and local noise variations. The headquarters frequency manager has large numbers of new circuit frequency requirements to satisfy, many with bandwidth requirements up to 12 kHz. New circuit requirements originate with the creation of new countries as well as with almost every reorganization or establishment of military commands and international economic or military treaty bodies. It has been estimated that the demand upon the HF band has increased by 300 percent in the past 20 years. Multiple assignments and extensive sharing are thus inevitable. Users are being placed under increasing national and international pressure to present justification for retaining all existing assignments in the HF band.

(2) Time and Geographic Sharing. Of the two modes of frequency sharing, time, and geographic, geographic sharing is the only one practical for many frequency assignments due to the around-the-clock nature of many operations. This is true in all portions of the spectrum from LF beacons to SHF radars, particularly in the case of military operations which are either operational 24 hours a day or must be maintained in a constant state of readiness. Problematical in geographic sharing, however, is the variable nature of radio wave propagation conditions, especially as regards the ionosphere. These variations may result in periodic harmful interference among users of the same or adjacent frequencies. Planned geographic sharing is more complex in the case of mobile operations. Mobile service assignments may be "pooled" in such a way as to ensure increased sharing, regardless of deployment. This concept is reflected extensively in the latest edition of JANAP 195. "Hubbing", the use of assigned complements for a multiplicity of point-to-point circuits emanating from a given source, is

also employed extensively. Ship-to-shore tactical assignments are further amplified in OPNAVINST 2410.23. While there has long been an interference problem in the HF band due to propagation variations, expansion of high powered LF and VLF systems, increased use of high powered radar and radio control systems (UHF and above), and the advent of space and scatter systems in the VHF and UHF bands increase the probability that these systems will also cause and/or receive harmful interference.

(3) Assignment Coordination Delay. The time delay in effecting coordination of frequency assignments is inevitable and creates a real problem of Navy standards of responsiveness. Rapid wartime communications electronics expansion cannot be restricted by the same delays. The importance of frequency resources in contingency planning is thus a paramount consideration. The time between receipt of a valid frequency requirement in Navy headquarters until assignment of a suitable frequency may vary from minutes in less congested portions of the spectrum to several months in bands of great demand. The amount of time required for negotiations will depend upon several factors, e.g., does the Navy have authority to use the desired frequency with similar power and emission in the desired terminal areas, is the intended service allocated on a primary basis in the desired frequency band, and particularly, does the area of intended use involve a foreign sovereignty with whom coordination must be effected?

Variations among sovereign administrations as to frequency coordination procedures, as well as the political atmosphere at any given time, may serve to further compound the problem.

(4) Obstacles to Reallocation. In the best interest of overall spectrum efficiency, many services in saturated frequency bands might be shifted to less saturated bands, within the technical parameters of the operations concerned. This step has been deemed necessary and so ordered in several instances (certain radar and telemetry bands are recent examples). Opposition to major reassignment or reallocation actions is quite strong many times, and justifiably so. A serious consideration involves plant investment. Other primary factors are the time and budgetary support inherent in design, development, and installation of hardware necessary for a service to function in a significantly different portion of the RF spectrum. The prospect of having to negotiate new complements of frequencies for an established service may also be a deterrent to considering major change. The lengthy time required for negotiation in addition to the loss of latent priority of older frequency assignment registrations or agreements are further considerations. The severity of this problem may be evaluated by the extent of involvement in the following areas:

o Change of Table of Allocation of bands to radio services

International
National
Intra-Military

o Operation of many units of similar equipment; i.e., many required in case of communications.

o Proposed re-accommodation or new service conflicts with expanding authorized service in one or more regions of the world.

(5) Communications. Frequency spectrum congestion and expanding communications requirements within the foreseeable future dictate the need for optimizing tuning resolution capability and maximum practicable frequency stability in radio communications equipment. Navy communications equipment currently being developed for operation in the 14 kHz to 2 MHz range, the 2 to 30 MHz range and the 225-400 MHz range shall have the capability to tune in accordance with the latest standards and instructions.

(6) Other Electronics. Certain OPNAV Instructions have been promulgated which require all electronic equipment design agencies to consider the elimination or reduction of interference in the design of equipment under their cognizance. In an effort to provide interference free operation as well as efficient utilization of frequency bands allocated for radar use, minimum radar engineering design requirements have been developed and set forth in MIL-STD-469.

d. In order to select frequencies for new equipment with the object of avoiding interference, the planner should have information on other users of the spectrum. The following publications may be consulted to obtain the required information:

o International Frequency List (IFL): Seven periodically updated volumes.

o IRAC Station List: Six periodically updated volumes.

o FCC Non-Government Station List: Nine volumes.

o U.S. Military Joint Radio Frequency Allocation Plan, JANAP 141.

o National and International Allocation Tables.

o Navy Master Copy, JANAP 195.

o Navy Master Frequency Clearance and Authorization Record (updated daily, complete master index).

o Quarterly Usage Report IBM Extracts.

o Frequency Coordination Card Files.

o Files of IRAC (FAS) Dockets.

o Interference Report Case Files.

o Frequency Lists of Unified Commanders and Joint Missile Test Ranges (PACOM FAU, EUCOM FAU, PACMISRAN, etc.).

4.5.2 Technical Factors

Frequency engineering can be thought of as the technical component of spectrum management. It may be defined as the process of selecting specific frequencies or bands of frequencies to be used for the performance of specific communications electronics services or functions. The selection of frequencies within the requirements of a particular system or equipment is primarily based on the goal of interference-free operation of all systems in the electromagnetic environment.

Other important considerations are conservation of the electromagnetic spectrum and future frequency requirements of the system.

a. Class of Service Considerations. The selection of a frequency band for a specific circuit is generally determined by the transmission properties of the band, the availability of frequencies within the band, the type of equipment available, and other factors. Selection criteria for the various bands have been documented in DNC-14 series, NAVELEX 0101,103, and other service publications, engineering texts, and papers. A brief discussion of the various bands follows.

b. Propagation Characteristics. Table 4-1 depicts the propagation characteristics of the various portions of the RF spectrum. Essentially, both sky waves and ground waves are generated at any frequency from almost any antenna. However, one or the other may be so minute as to be negligible. Along the earth's surface, the maximum distance a ground wave is effective is inversely proportional to the wave frequency. Also, ground waves undergo deviation from normal straight line travel by lower atmosphere refraction, bending of waves through a

Table 4-1. Propagation Characteristics of the RF Spectrum

	BAND	PROPAGATION CHARACTERISTICS	TYPICAL USES
Below 3 kHz	ELF	Same as LF	Very long distance point-to-point (greater than 1000 nautical miles)
3-30 kHz	VLF	Same as LF, except attenuation equally low, day or night; reliable	Very long distance point-to-point. Fleet broadcast communications
30-300 kHz	LF	Primarily ground waves low attenuation, reliable, daytime absorption of sky waves greater than at night	Long and medium range (50 to 1000 nautical miles, point-to-point communication, marine, Navaids
300-3000 kHz	MF	Ground waves but some ionospheric sky waves, attenuation of sky waves low at night and high in daytime. Subject to ground-sky wave interference for distances less than 500 nautical miles.	Broadcasting, marine communications, Navaids, harbor telephone, medium and short range
3-30 MHz	HF	Transmission over great distances, depending on ionosphere. Varies greatly with time of day, season, frequency and portion of solar sunspot activity cycle. Subject to ground-sky wave interference at short distances	Moderate and long distance communications of all types
30-300 MHz	VHF	Sporadic ionospheric effects occur during high portion solar cycle	Short distance, line-of-sight communication, television, FM broadcasting, Navaids, radar, over-horizon "scatter" communications, aero-Navaids
300-3000 MHz	UHF	Same as EHF	Short-distance communication, radar television, aero-Navaids, point-to-point relays, over-horizon "scatter"
3-30 GHz	SHF	Same as EHF	Short-distance communication, radar, point-to-point relay systems, Navaids, satellite relays
30 GHz	EHF	Substantially straight line propagation analogous to that of light waves. Unaffected by ionosphere	Radar, radio-relay Navaids

particular propagation medium, diffraction (phenomena of waves bending around objects) and propagation along the curved surface of the earth because of the earth's conductivity, property of matter which enhances propagation of electromagnetic waves; all of which extend the distance of propagation beyond the line-of-sight distance. Sky waves undergo travel deviation in the atmosphere to varying degrees as a result of refraction, scattering, and absorption.

The ionosphere, a region of the upper atmosphere approximately 40-250 miles above the earth's surface, is formed primarily by the ionizing effects of the sun's ultraviolet light. It is possible to predict to some degree, the intensity of the ultraviolet light radiated by the sun, hence, the degree of ionization and the behavior of radio waves which use the ionosphere as a propagational media. Cosmic rays, X-rays. meteors, and actual particle radiation from the sun also have an effect on the ionization of portions of the ionosphere. At times this ionization is sufficiently great to cause disruption to long distance radio communications.

For a given operation, frequencies calculated as capable of propagating along the particular path should be selected from an authorized resource such as JANAP 195. The high frequencies required for long-range communications and data circuits will vary according to time of day, season and portion of the solar activity cycle; therefore, such circuits inevitably will have several frequencies assigned as a complement to provide for 24 hour operations.

There is significant use of both manual and computerized ionospheric predictions, long and short term, in the design, planning for, and operation of radio communications systems. Long-range predictions are published by countries such as Great Britain, Canada, Japan, and the United States. The real-time requirements of traffic control centers dictate that some way be found for updating the long-term predictions used in assigning frequency complements. Related projects and planned advanced naval communications complexes are oriented toward meeting this need.

c. Phenomena Of Naturally Caused Interference. Precipitation static and atmospheric, solar. and cosmic emissions all have an adverse effect upon the signal level required to receive intelligence. Atmospheric effects are predominant for communications where frequencies below 20 MHz are involved. For frequencies above 20 MHz, receiver set inherent noise and cosmic emissions become predominant, and solar effects are noticeable. Cosmic emissions that penetrate the atmosphere generally interfere only in the 20-100 MHz range in quiet (low set noise) receivers at quiet locations. Solar emissions that penetrate the atmosphere are noticeable only on sharply beamed antennas during periods in the earth's rotation when such antennas are on particular bearings relative to the sun and affect all frequencies above UHF. Precipitation static and atmospheric phenomena result from electrostatic storm disturbances (thunderstorms) in the earth's atmosphere causing interference in bands utilizing ground and sky-wave propagation. Atmospheric effects are transmitted long distances via the ionosphere, losing intensity through attenuation. The effects originate primarily in the tropical zones and cause relatively little interference in the polar zones.

d. General Communications Service Characteristics

(1) Fixed Service. Frequency requirements for fixed services are related directly to distance along great circle paths between fixed earth terminal points. Long distances dictate the use of high frequencies where propagation is predominantly by sky wave (ionospheric layer reflection). Intermediate distances of 15-1000 nautical miles dictate the use of MF and LF where there are both sky and ground-wave propagation modes. Upper UHF and mid SHF bands previously limited generally to line-of-sight are now applicable to certain long haul applications through the development of microwave relay systems. Fixed paths are conducive to planned geographic sharing within the variations of natural radio wave propagation phenomena.

(2) Mobile Service. Frequency requirements for mobile services are related to a wide range of distances and also to the nature of the Mobile Service (Maritime, Land, Aeronautical). Long and medium distances dictate use of MF and HF. UHF above 60 MHz is best for land or sea short distance communications, while VHF/UHF is used for aeronautical short distance communications. Except for broad parameters, the mobile services are not particularly conducive to planned geographic sharing, especially when potential long distance requirements dictate the use of HF, which would increase the probability of harmful interference to other services.

(3) Broadcast Service. Frequency requirements are related primarily to the maximum effective coverage desired. This service is intended by definition, for the reception generally by the public throughout areas specified in the authorizations (licenses) for each station to which a frequency is assigned. Internationally, radio and television broadcast service stations use frequencies ranging from 150 kHz to over 800 MHz. The Navy's Fleet Broadcasts have corresponding requirements to serve all Fleet units within given Fleet Broadcast Areas, although recent state of the art and tactical developments have introduced improved VLF applications. Predicted coverage of broadcast service transmissions supports both time and geographic sharing of frequencies to a limited extent. Standard Time and Frequency Broadcast assignments of specific frequencies follow the same selection criteria; therefore, these assignments are widely promulgated.

(4) Radiolocation Service. Applications of radiolocation services are basically line-of-sight in nature. Of primary concern to the Navy frequency manager are the many radar, radio-command-control (drone) and similar requirements that demand broadband portions of the VHF, UHF, and SHF bands. To a lesser extent, some portions of the HF band are utilized for distance measuring and surveying equipments, such as LORAC and RAYDIST.

(5) Radionavigation Service. Two distinct services, Maritime Radionavigation and Aeronautical Radionavigation, are identified under this service category. These systems (Radio Direction Finding (DF), FM and Radar Altimeters, Navigational Radar, Homing Beacons, TACAN, LORAN, OMEGA, etc.) employ a variety of transmission characteristics and distance capabilities and require frequency support ranging from VLF to SHF. Band allocations have been established, due to safety-to-life considerations. on a national and international basis and may be appropriate for sharing with other services with the condition that harmful interference is not caused to the Radionavigation Service.

For Maritime Radionavigation, several LF and MF bands serve the beacon and position fixing requirements.

For Aeronautical Radionavigation, requirements are as follows:

o Homing Beacons:

Long range at the lower end of MF band (about 300 kHz adjoining Maritime Radionavigation beacons).

Short range at mid-VHF

o TACAN: 960-1215 MHz.

o Altimeters: Near 1700 and 4300 MHz.

o Radar: For air traffic control, ground control approach, tracking, etc., several portions of the spectrum in the upper end of the UHF and in the SHF band.

(6) Telemetry And Space Service. Telemetry is usually further identified with another service designation with which the operation is associated, such as Meteorological, Space, Oceanographic, Aeronautical, etc. Nearly all the requirements are line-of-sight and are met in several ranges of frequencies in the SHF band. Distances involved in some ocean buoy to shore transmission require high frequencies. Special frequency allocation provisions in the crowded HF communications bands are under consideration at the international level. Reflected in the International Table of Frequency Allocations, are expanded provisions for space research and communications operations.

4.5.3 Considerations for Frequency Selection for EMC

The selection of frequencies to provide the most reliable and least interfering transmission for those locations having multiple transmitter-receiver configurations requires consideration of many factors. Numerous methods of selecting frequencies for specific service type have been devised, based on various interference criteria, e.g., interference margins, mutual interference matrices, etc. These will be discussed in greater detail in subsequent chapters of this document. Because of the complexities of multiple collocated equipment, many of these methods have been conceived for use with automated, data processing equipment. Also, because of the random nature of both the propagation medium (particularly for HF service) and the equipment coupling mechanisms, the use of statistical techniques has become common. Paragraph 1.5 describes the services provided by the DOD Electromagnetic Compatibility Analysis Center in the area of frequency assignment and selection. Important considerations are listed as follows:

a. The determination of susceptibility to emissions of all systems in the electromagnetic environment.

b. The determination of transmitter-receiver frequency separation requirements.

c. The determination of geographic space separation requirements for combinations of systems-equipments (interference predictions).

d. The determination of frequency groupings or channelizations to satisfy the separation requirements and to minimize intermodulation products and spurious outputs and responses.

e. A guard band, several RF channels wide, may be established between transmitting and receiving frequencies. If the radio sets used have numerous spurious outputs and responses, a simple guard band may be insufficient.

f. Adjacent channels should not be used by receivers in the same installation. If the wanted signals for two receivers are of widely different magnitude, it may be necessary to separate the two signals by more than one channel. Some radio sets may require frequency separation of more than one channel.

g. Re-use of the same frequency at other locations depends on the transmission properties of the frequency band in question. Some channels or channel groups in the HF band are set aside for long-distance, high-powered clear channels, and others are re-used at more frequent geographic spacing for low-powered, short-distance transmission.

h. For duplex operation provision should be made for wide frequency separation between any transmitting frequency and any receiving frequency at the same site. However, widely separated frequencies are not always available.

i. Frequencies should be selected so that the frequency difference between any pair of frequencies is unlike the difference between any other pair. In some cases, the specific operating frequencies can be chosen so that no third-order product frequency coincides with a receiving channel frequency at the same or a nearby site. Frequencies selected in this manner may result in a setup that is inflexible.

j. Sets of channels that can be used without third-order intermodulation difficulties are listed in table 4-2. It is assumed in the table that the frequency spacing between consecutively numbered channels is a constant; therefore, the difference between channels 1 and 2 is the same as the difference between channels 2 and 3, etc. This table is applicable throughout the spectrum, if the frequency spacing between channels is kept constant during the selection of frequencies at any one installation. In the use of this table, any single constant can be added to all channels in a given set; therefore, if three channels are wanted, these may be 1, 2, and 4, or 71, 72, and 74; 1, 5, and 7, or 31, 35, and 37; etc.

k. Often it is unnecessary to crowd the channels together. Crowding increases the likelihood of interference through the lack of selectivity in the radio equipment or because of spurious output and response. Channel assignments spaced farther apart and not having third-order interference can be obtained in either of two ways. First, a set of channels can be chosen from a larger set in table 4-2. For example, if six channels are wanted, they could be chosen from the set that has ten channels. One such selection might be channels 1, 12, 27, 40, 48, and 62. Second, the table can be modified by multiplying the channel differences by any whole number.

l. The channel selection groups in table 4-2 can be used to select frequencies for duplex operation by taking two equal subgroups from any one set in the table. In addition to the sets of frequencies given in the table, other sets exist that are free from third-order interference.

Table 4-2. Sets Of Channels Having No Third-Order Interference

Number of channel assignments*	Channel numbers
3	1,2,4,
4	1, 2, 5, 7
5	1, 2, 5, 10, 12
6	1, 2, 5, 11, 13, 18
7	1, 2, 5, 11, 19, 24, 26
8	1, 2, 5, 10, 16, 23, 33, 35
8b	1, 2, 8, 12, 27, 50, 78, 137
9	1, 2, 5, 14, 25, 31, 39, 41, 46
10	1, 2, 8, 12, 27, 40, 48, 57, 60, 62
11	1, 2, 5, 11, 23, 39, 59, 70, 78, 83, 85
12	1, 2, 5, 11, 23, 39, 64, 84, 95, 103, 108, 110
13	1, 2, 5, 11, 23, 39, 53, 80, 100, 111, 119, 124, 126
14	1, 2, 5, 11, 23, 39, 53, 88, 115, 135, 146, 154, 159, 161
15	1, 2, 5, 11, 23, 39, 53, 88, 120, 147, 167, 178, 186, 191, 193
16	1, 2, 5, 11, 23, 39, 53, 88, 117, 149, 176, 190, 207, 215, 220, 222
17	1, 2, 5, 11, 23, 39, 53, 88, 117, 157, 189, 216, 236, 247, 255, 260 262
18	1, 2, 5, 11, 23, 39, 53, 88, 117, 162, 202, 234, 261, 281, 292, 300 305, 307
19	1, 2, 5, 11, 23, 39, 53, 88, 117, 162, 217, 253, 293, 325, 372, 383 391, 396, 398
21	1, 2, 5, 11, 23, 39, 53, 88, 117, 162, 224, 279, 315, 355, 387, 414 434, 445, 453, 458, 460
22	1, 2, 5, 11, 23, 39, 53, 88, 117, 162, 224, 321, 376, 412, 452, 484, 511, 531, 542, 550, 555, 557
23	1, 2, 5, 11, 23, 39, 53, 88, 117, 162, 224, 304, 401, 456, 492, 532, 564, 591, 611, 622, 630, 635, 637
24	1, 2, 5, 11, 23, 39, 53, 88, 117, 162, 224, 304, 361, 458, 513, 549, 589, 621, 648, 668, 679, 687, 692, 694
25	1, 2, 5, 11, 23, 39, 53, 88, 117, 162, 224, 304, 358, 415, 512, 567, 603, 643, 675, 702, 722, 733, 741, 746, 748

* Each set of channels has one pair of adjacent channels: Nos. 1 and 2. To avoid using adjacent channels omit No. 1 or No. 2

b This set has neither third-order nor fifth-order interference.

CHAPTER 5

FUNDAMENTALS OF EMC/RADHAZ

5.1 BASIC EMC CONSIDERATIONS

In analyzing the EMC effects of an installation there are many potential sources of interference; these are discussed in subsequent paragraphs to assist in the EMC analysis.

Any circuit, device or equipment carrying an electric current must be thought of as a potential source, or receptor of emissions. Figure 5-1 shows the three basic components of an interference situation; the interference source or generator of the undesired signal, the transfer medium or coupling mechanism, and the receiving element or susceptible device exhibiting the undesired response.

Compatibility is achieved by: minimizing the generation of potential interference emission at the source, minimizing the transferred signal by isolation, shielding, and other techniques, designing the receiving element to be non-susceptible to the emission; or combinations of the preceding.

5.1.1 Interference Generation

Interference-causing signals are associated with time-varying electrical or magnetic fields directly related to rates of change of currents with time. A source producing current changes generates either periodic signals, impulse signals, or a signal which varies randomly with time.

Generally, interference-causing signals may be grouped into two categories, narrowband or broadband (random and impulse).

Typical sources of random signals are fluorescent lamps, thermal noise, and atmospheric noise; typical sources of impulse signals are switches, ignition devices, and power lines.

Pulsed signals represent one of the most common sources of EMI. The more rapid and abrupt the rise and fall of the pulse, the greater the likelihood the interference will be generated over a broader frequency spectrum.

Random and impulse type signals are similar, in that they are distinguished by the partial or completely overlapping nature of the random signals versus the distinct individual pulses characterizing impulse noise.

As mentioned previously, potential interference signals may also be periodic in nature. Periodic signals are characterized by a systematic or cyclic repetition of the amplitude variation with time. Typical sources are oscillators, communications transmitters, and radar transmitters. Although all potentially interfering signals can most obviously be thought of as functions of amplitude versus time, each can also be equivalently thought of as a function of amplitude versus frequency. Often attenuation and other propagation phenomena between the interference source and victim device are different for different frequency components of the interference signal. Most significantly, the response of many devices to interfering energy is a function of frequency.

5.1.2 Interference Sources

Interference sources may be classified into two broad categories: natural and manmade. The latter can be subdivided into functional sources and incidental sources.

Functional sources of interference refer to equipments having the intentional generation of a useful signal as their prime function. Communication and radar transmitters, oscillators, and signal generators are examples.

All radar and communications transmitters, radionavigational systems beacons, etc., intentionally radiate signals for the purpose of conveying information. These signals are potential major sources of interference to receiving devices in the electromagnetic environment. There are three major types of potentially interfering signals from functional sources: intentionally radiated signals, harmonically related spurious emissions and non-harmonically related spurious emissions.

a. Functional Sources. A typical example is transmitter-generated signals. Several basic sources of spurious frequencies exist within a transmitter. These basic sources emit spurious radiation that can be divided into:

o Harmonics of the transmitter fundamental (f_o).

o Harmonics of the transmitter master oscillator frequency (f_{mo}). These outputs will occur between harmonics of f_o for those transmitters having a master oscillator frequency below the fundamental frequency.

o Nonharmonically-related outputs (for example, those that occur in a magnetron).

o Noise.

Although each of the listed types of spurious radiation exists, it can be stated that in all except high-power transmitters, the noise level is generally not significant relative to the other three types.

In the first two types of spurious radiation (the harmonically-related spurious), these signals are primarily generated from oscillator and multiplier stages of the transmitter, from power amplifiers, and from mixer or frequency synthesizing stages of the transmitters.

In some transmitter systems, a mixer is used to generate the system fundamental output frequency or a submultiple thereof. When this is the case, spurious emissions are generated in the mixer. To illustrate what specific frequencies are generated, consider as an example the generation of a transmitter fundamental frequency in a transmitter-receiver system which uses the local oscillator in both the transmitter and receiver sections. If the fundamental output from the transmitter is ($f_1 + f_{LO}$), where f_{LO} is the local oscillator frequency and f_1 is a crystal oscillator frequency, then signals are generated at ($f_1 - f_{LO}$), ($2f_1 + f_{LO}$), ($f_1 + 2f_{LO}$), etc. due to the nonlinearities of the mixer. From this example, it can be seen that many spurious signals are generated and, hence, tuned circuits are required following the mixer stage in order to attenuate the undesired frequencies. For most equipments, these spurious or harmonic signals must be investigated and attenuated if found to cause interference.

Harmonically-related spurious emissions generated by the methods just described, along with high-power fundamental frequencies of any nearby transmitters, can generate adjacent and co-channel interference in receiving systems. Usually, direct co-channel signals (without intermodulation or mixing occurring) can be traced to spurious emissions, rather than from the fundamental of a distant transmitter, since frequency allocation plans usually prohibit co-channel operation unless the channels are on a time-sharing plan.

It should be pointed out that when discussing spurious emissions, in the form of harmonics of the transmitter, the receiving devices to be considered include intentional receivers of electromagnetic energy as well as other devices that are susceptible to the effects of electromagnetic radiations.

Basically, nonharmonically-related spurious emissions are generated primarily from high-power oscillator sources such as magnetrons used in radar transmitting systems.

b. Incidental Sources. This type of interference is associated with all equipments or devices which do not generate a useful signal as their prime function. Some of the more important sources include:

o Switching devices

o Ignition systems

o Rectifiers and regulators

- o Brush and commutator type electrical machinery
- o Power lines
- o Fluorescent and other gas filled lamps
- o Welding devices
- o Industrial equipment, e.g., RF heaters
- o Arcing and corona.

A brief discussion of the interference characteristics of some of these devices follows.

(1) Switches. All switches cause essentially the same types of interference whether electrical, thermostatic, electromechanical or electronic in operation. The switch is essentially a device that can abruptly change its electrical impedance from zero to infinity or from infinity to zero. This sudden change causes current and voltage transients throughout the circuit resulting in generation of broadband emissions which may cause interference. In the case of manually actuated electrical switches, the emission produced is generally of relatively short duration unless there are capacitors or inductors in the circuit. Usually such emission is not repetitive or if it is, repetition is at a slow or irregular rate. Switching interference is more severe when large current values are involved because arcing across switch contacts when making or breaking circuits greatly intensifies the interference in both level and duration.

Electromechanically actuated switches such as relays, vibrators, and buzzers create exactly the same type of broadband emissions as do manually actuated switches, but usually at a faster rate. Repetitive interrupters, such as vibrators, produce the same broad spectrum emission on a continual basis.

Thyratrons and similar gaseous discharge tubes are frequently utilized for switching purposes because of their extremely fast operating time. Because of this fast operating time, however, such tubes create very substantial amounts of interference, particularly when handling large currents. Thyratrons having turn-on times in the order of 1 μ sec are quite common. Just as with manual switches, thyratrons being operated infrequently can cause considerable broadband interference, though only for a relatively short time duration. Thyratrons, when discharged repetitiously at a high rate, such as when used for the control of motors and other equipment, can create very intense broadband interference on a continuous basis.

Silicon-controlled rectifiers are related to the transistor in much the same manner as the thyratron is related to the triode. These devices are capable of handling substantial amounts of power and are either nonconductive or conductive, depending upon their bias. When triggered, the controlled rectifier reaches its maximum state of conductivity very rapidly. The result is the production of a wide band of electromagnetic interference. Because controlled rectifiers are often used as repetitious switching devices in static inverters and power converters they can be a continuous source of broadband interference.

(2) Ignition Systems. Ignition systems are strong producers of EMI characterized by high-amplitude, short-duration pulses which exhibit broadband properties. The sources within an ignition system known to produce interference signals are the breaker points, spark-plug wiring, distributor, generator and voltage regulator. These signals can generally be regarded as being of the impulse type.

Figure 5-2 shows a typical spark-plug voltage waveform from an automobile ignition system. Illustrated are the points along the wave at which the automobile distributor points open, the position at which the spark-plug gap ionizes and fires, and the position at which the distributor points close. Also illustrated on the waveform are the two major components of the ignition spark, the capacitive and inductive components. To determine the contribution to interference by each component of the ignition spark, an examination of the current during each

phase of the pulse waveform is required. The current associated with the capacitive component of the wave is highly oscillatory and covers a wide frequency range from HF through UHF. Hence, the major source of interference from the ignition system is due to the capacitive component of the ignition spark. The inductive component contributes a negligible amount to the interference being radiated except possibly at the lowest frequencies emitted. Restrictions on the use of vehicles at installations are issued by the activities.

(3) Rectifiers. Rectifiers have been described as nonlinear circuit elements having the property of passing a greater current in one direction than in another.

Rectifiers can produce at least two types of interference: harmonic and broadband. Harmonic interference is generated as a result of the nonlinear characteristic of a rectifier. The signals produced include the applied frequency, its harmonics, and associated intermodulation products. These often extend over hundreds of megahertz throughout the spectrum. When an applied signal is nonsinusoidal in waveform or of high frequency, the cutoff time of the rectifier becomes very short, and it generates broadband emission.

Mercury vapor and gaseous-type rectifiers can generate interference because of the manner in which they function. The continual establishment of new conduction paths through mercury within the tube and the continual breakdown of existing paths, all with considerable arcing, create interference in addition to the usual harmonic and switching type interference produced.

(4) Electrical Equipment. Electrical equipment constitutes a serious source of broadband as well as narrowband interference. Broadband emission is generated during the commutation process by the brushes and the armature, arcing in bearings, friction between moving parts, internal arcing, and control windings. Narrowband emission arises from poor machine symmetry causing the generation of harmonic frequencies.

Brush-type motors are the most offensive generators of potential interference of all the types of rotating machinery. Machines that use sliprings, such as induction motors and alternators, produce emissions that are generally much lower in amplitude relative to those produced by the brush-type motor. The most commonly used brush-type motor is the universal motor. This motor has the convenient ability to run on either AC or DC with similar characteristics (provided both stator and rotor cores are laminated). Because of their rotation speeds (1500 to 15,000 r/min) and their versatility, these motors are used in a number of domestic as well as industrial jobs. Portable electric drills, saws, and sanders, as well as electric shavers, fans, blenders, clocks, and a host of office appliances all make use of universal motors.

Basically, the emissions generated by these sources can be considered random, since the emissions are generally high-speed impulse-type signals. The frequency output of a brush-type motor ranges from 10 kHz to 1000 MHz.

The devices should not be used in the vicinity of electronic equipment unless they comply with applicable EMI requirements, such as those specified in MIL-STD-461 .

(5) Power Lines. A source of impulse noise with a high duty cycle that is generally important only at frequencies below 100 MHz is a power line. Power lines generate 60 or 400-Hz noises in receiving systems primarily due to malfunctions, faults in insulating material, or loss of line insulation. Discontinuities in a power line, a prime source of corona emissions, can be found at the high-power insulator tie-off points along the line. It should be emphasized that power line emissions can become extremely important if discontinuities or malfunction along the line occur. Requirements for control of radiated emissions from overhead power lines on Naval installations are detailed in MIL-STD-461. In addition, care should be exercised in adhering to minimum separation from commercial power lines, such as presented in other Naval Shore Electronics Criteria Handbooks.

(6) Fluorescent and Other Lamps. Fluorescent lamps, mercury vapor lamps, sodium lamps, and neon signs are known causes of interference. Fluorescent and neon lamps produce pulse-type interference which may be conducted by and radiated from the power supply circuit. Mercury arc lamps and sodium lamps produce arc-type (impulse) radiation. In these last two types of lamps, the energy level is high due to the high currents and voltages required for operation. Usually, line filters and shielding are required for use in all such installations. The generated interference from these sources has been shown from tests to be most severe at frequencies below 10 MHz.

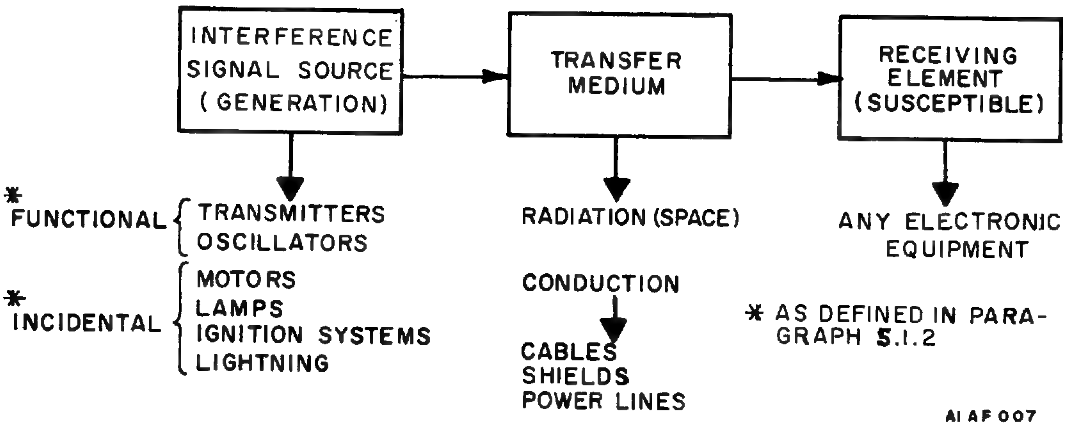


Figure 5 - 1. Three Basic Components of Interference

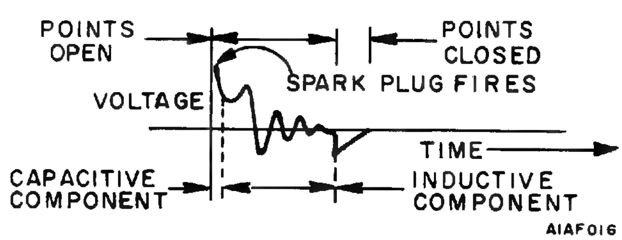


Figure 5 - 2. Typical Voltage Waveform Across Automobile Spark-Plug Gap

(7) Natural and Inherent Sources of Interference. These refer to phenomena originating in the earth's atmosphere and beyond, and to the noise inherent within electronic equipments. These do not generally cause interference in equipment other than sensitive communication and radar systems because of the limited power levels associated with natural sources. CCIR Report No. 322 provides information for determining natural emission levels and is useful in performing EMC site surveys.

(a) Atmospheric Interference. Atmospheric effects are erratic in character, consisting of short, randomly recurring pulses completely without regularity in phase or amplitude, and energies not confined to a particular band. The average power level is relatively constant during any given hour although it may vary considerably over a longer period of time. Atmospheric fluctuations depend on such things as frequency, time of day, season, location, and weather conditions.

Atmospheric emission occurs predominantly in frequency regions below 50 MHz and it dominates all other natural interference sources below 30 MHz. It is usually the limiting factor in communications within this spectrum and decreases rapidly above 30 MHz. Figure 5-3 shows typical daytime and nighttime atmospheric emission levels as measured by a ground antenna.

Reception of atmospheric emissions may be reduced by decreasing antenna beamwidth, sidelobe level, and response bandwidth, while increasing antenna directivity and transmitted power. The values presented on figure 5-3 are typical for tropical ground stations.

(b) Cosmic Interference. Cosmic emission originates beyond the earth's atmosphere and is generated, to some degree, in all areas of the universe. Like atmospheric emission it consists of short, randomly recurring pulses completely without regularity in phase or amplitude, and its energy is not confined to a particular band. The cosmic signal intensity varies with celestial longitude and frequency. On the surface of the earth, cosmic-caused interference is effectively confined to UHF and VHF frequency regions because of absorption and reflection of other frequencies. The true intensity range of this phenomena above ionosphere shielding is as yet unknown for lower frequencies. It is most prevalent below 250 MHz, while solar-caused interference extends beyond 30,000 MHz. Major sources of galactic phenomena are the Milky Way and the sun. By using narrow bandwidth antennas and the highest frequency, interference from these sources can be greatly reduced. Figure 5-3 indicates typical values of cosmic power levels measured by a skyward-directed, high-resolution antenna.

(c) Solar Interference. Solar radiation emanates from sources located in the chromosphere and corona of the sun. The sun behaves, however, very much like a black-body radiator at 6000° K for frequencies in the infrared and visible light spectrum, although it emits considerably more radiation than can be accounted for by black-body analysis at lower frequencies. The lower frequencies are generated in the corona and the higher frequencies in the chromosphere, with both contributing radiation at intermediate frequencies. Because the source location varies in surface depth, the apparent temperature for each frequency also varies accordingly. The intensity of solar radiation fluctuates with a periodicity of weeks or months and corresponds to sunspot activity. It increases during periods of sunspot activity and decreases when there is less sunspot activity. These periods of increased radiation last several days at a time. At such times, interference levels may be 10 to 20 dB greater than the normal level of a quiet sun. At lower frequencies, solar radiation does not fluctuate as much as it does at high frequencies. Radiation is first noticed at the higher frequencies; afterwards, at the lower frequencies. The radiation generally occurs in bursts that are greater in intensity than the general background interference level. The radiation accompanying these storms is strongly circular in polarization. Accompanying solar flares are outbursts that last several minutes and increase the emission level of the sun by many orders of magnitude. Sometimes the frequency spectrum of these outbursts is quite wide and involves the major portion of radio frequencies now in use. Figure 5-3 shows power levels for an active, quiet, and violent sun. These levels were determined for an antenna oriented toward the sun with a beamwidth nearly equal to the solar diameter.

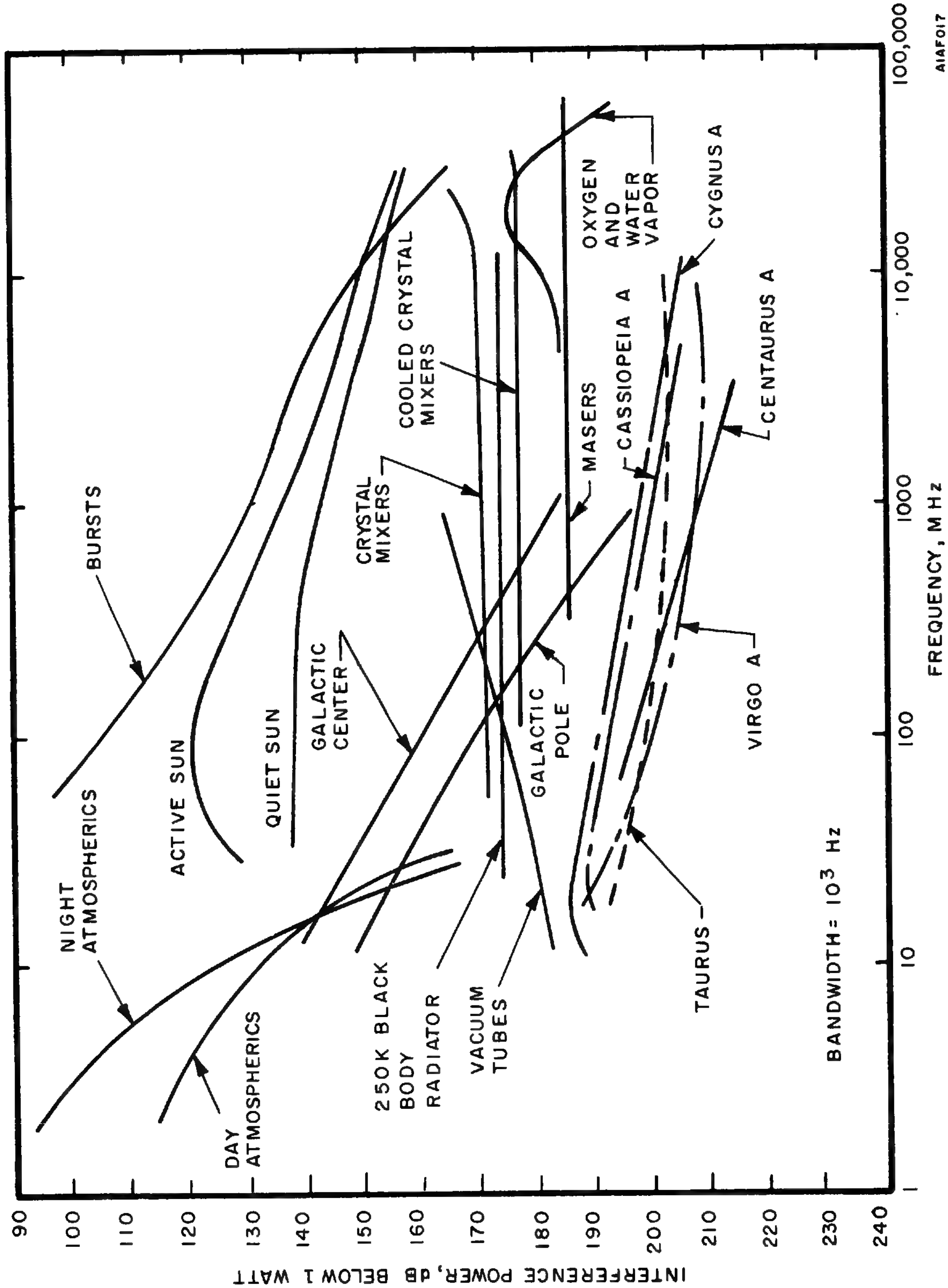


Figure 5-3. Interference Power vs. Frequency for Various Sources

(d) Galactic Point Sources of Interference. Discrete emission sources of extraterrestrial origin have been observed since 1946. When a source is sufficiently small, it is considered a point source. Most point sources are termed radio stars, but have not yet been shown to correspond to actual optically visible stars. Usually, if a source subtends an angle less than one degree, it is considered localized, and if more than one degree, an extended source.

Many radio stars have been discovered in the last decade since the advent of radio astronomy. The use of low-noise receivers increases the possibility of discovering more radio stars Only a few of these sources, however, emit electromagnetic energy of sufficient magnitude to warrant consideration as important sources of background interference to present receiving systems. The levels detected from five of the more important radio stars are shown on figure 5-3. The values used were converted from flux density to power, assuming an effective capture of one square meter.

(e) Inherent Sources of Interference. This source of interference energy was described as self-generated noise within the receiving system. Generally, this noise can be traced to thermal noise, shot noise, partition noise, flicker noise, collision ionization, and induced noise.

Thermal noise is primarily caused by agitation of electrons due to heating, while shot noise is due to the random emission of electrons from a cathode. Partition noise primarily arises in pentodes from the random fluctuations in the current division between the screen and the plate. Flicker noise is due to the spontaneous emission of particles from an oxide-coated cathode (usually more noticeable at low frequencies) and collision ionization refers to a random noise generated by the ionization of a few gas molecules which remain in a vacuum tube or are present in a gas-filled tube. Induced noise is prevalent primarily at ultra-frequencies and is a random noise generated from fluctuations in the induced current in the electrode leads of a tube.

Each of the previous noise descriptions has been applicable to tube-type noise. However, many of the noises described are also found in semiconductor systems. A transistor emits thermal noise and random noise due to the random motion of majority carriers crossing emitter and collector junctions. Also, a partition effect due to the fluctuations in the division of current between the collector and base is generated. The noise power in a transistor is inversely proportional to frequency, and is dependent on the quiescent conditions of the semiconductor material.

5.1.3 Transfer Medium

Paragraph 5.1.1 provided information on the nature and sources of interference-causing signals. To cause interference, a potentially interfering signal must be transferred from the point of generation to the location of the susceptible device and may occur over one or several paths. Basically, there are only two modes of signal transference, conduction or radiation.

a. Conducted Emission. Conducted emission refers to signals that are transferred over common interconnections between a source and a receiving device, i.e., wiring, cabling, or any metallic structure. A complete circuit path is necessary for this to occur, that is, there must be a direct connection between two circuits, and in addition, a return path. The return path can be via a lead wire, a mutual impedance, or a common ground plane or return. Undesired signals coupled by ground loops or by common connections are especially prevalent. Figure 5-4 shows a source coupling to a receiving device by conduction through common power supply wiring.

The propagation of conducted emission generally conforms to conventional circuit theory. The magnitude of a resulting current, therefore, depends on total loop impedance and the voltage sources within the loop.

(1) Circuit Coupling. Two circuits are said to be mutually coupled whenever voltages or currents in one circuit produce corresponding voltages or currents in the other circuit.

The sharing of a wire or a junction point between two or more circuits can result in common impedance coupling, wherein current in one circuit causes a voltage to appear in another circuit. The interference voltage level so produced is dependent upon the magnitude of the common impedance. Thus, circuits characterized by high impedances (and low current levels) are highly susceptible to interference.

Every portion of a circuit has capacitance between it and every other portion, so that any voltage variation within the circuit tends to produce current through these capacitances. Two conductors in close proximity, for example, will have a capacitive reactance between them, whose effective value varies with the distance between the conductors, their size, and the frequency of the interfering signal. Note that the effect of capacitive coupling increases with increasing frequency. The interposing of a shield (or using shielded wires in the case of conductors in proximity) will attenuate the current flow, but will not eliminate the capacitance.

Since the various circuits in any equipment exist as closed loops, mutual inductances are present which act as the mechanism for interaction between the loops. This interaction between loops is called inductive or magnetic-field coupling and may be thought of as a transformer action between the interference source and the sensitive circuit. Thus, where a current variation occurs in one circuit, a varying electromagnetic field is produced which induces a voltage into any other circuit loop linking the flux of the field. The amplitude of the induced voltage is directly proportional to the area of the circuit loop which encloses the flux from the first circuit. Circuits characterized by low impedances (and high current levels) are particularly susceptible to magnetic field coupling. Note that the effect of inductive coupling increases with increasing frequency. The interposing of a shield or the repositioning of the circuit elements or wiring can reduce inductive coupling to zero.

The coupling effects described, although actually classed as transmission by radiation, are analytically described using the methods of circuit analysis. In those cases, however, where the separation distances become relatively large compared to the circuit coupling elements, circuit analysis equations become invalid, and exact relationships must be obtained through the use of electromagnetic field theory.

b. Radiated Emission. Electromagnetic fields are produced by time-varying currents through circuit elements, and are radiated outward from the elements according to the laws of wave propagation. Interference occurs when the radiated field encounters other circuit elements, causing currents that produce unwanted effects to be induced in them. Since both the source, or radiating element, and the receiving element can be thought of as antennas, the transfer mechanism can be analyzed by considering the basic properties of antennas, their corresponding electromagnetic fields, and the effects of the propagation medium on the radiated signal.

It has been found that, in order to define the properties of the field produced by an infinitesimal antenna element, the space surrounding the antenna can be divided into two major regions, the near field and the far field, as illustrated in figure 5-5. The near field region is subdivided into the static field region and the induction field region.

The static field exists in the volume immediately surrounding the element, and is so called because the field energy in this region remains static, in a manner similar to the energy stored in the field of an inductive coil. The field intensity in this region varies as $\frac{1}{r^3}$ where r is the radial distance from the element.

The induction field region exists further out from the antenna and is characterized by the cyclic outward and inward flow of energy as the field expands and collapses. The field intensity in this region varies as $\frac{1}{r^2}$.

The static and induction fields make up the near field region. The energy within this region is mainly reactive where no net outward flow of energy takes place. The relative shape of the antenna field pattern may vary appreciably from point-to-point.

At distances relatively far from the antenna element, the propagated energy can be regarded as existing as uniform plane waves having only transverse field intensity components. In the far field, as this region is called, the energy flow is real, i.e., no appreciable energy storage occurs, the field intensity varies as $1/r$, and the relative shape of the field pattern is independent of the distance from the antenna element.

To summarize, the radiation (or far) field region of space is that region in which the field strength is primarily a function of the inverse distance $(1/r)$ from the antenna. When the field strength magnitude becomes dependent on the inverse square of the separation distance, the near field begins and the induction field is defined. Moving closer to the antenna, the major field dependence is on higher-order terms of the inverse separation distance, i.e., terms of higher order than $1/r^2$. From the preceding discussion it can be seen that no exact boundary can be set for the transition distance between field regions. Each transition is a gradual one which depends on the variations of the field strength with distance.

Since transmission of an electrical signal involves propagation through a medium, the effects on the signal by the medium must be considered. During transmission, a loss is incurred due to scattering, absorption, reflection, and many other factors which, if great enough, can render the undesirable signal harmless, or if not great enough, can allow the undesired signal to reach the receiving device. Basically, it can be stated that, when a signal is radiated through the electromagnetic environment, the losses incurred in transmission are dependent on frequency, separation distance, (i.e., the distance from emitter of the electrical disturbance to the affected device), terrain over which propagation occurs, the electromagnetic properties of the medium, and many other variable factors. Many of the variable factors can change with time and thus introduce changes in the mode of propagation.

One of the most fundamental concepts of propagation loss is the free-space propagation loss. This loss is a lower limit on what should be expected when a signal is transmitted through space. This lower limit is very useful in the prediction of interference since it allows for the determination of a worse possible case of interference at a receiving device. More details on the usage of the free-space propagation loss factor will be given in the discussion of prediction methods. For the present, it will suffice to illustrate what is meant by free-space transmission loss by presenting the basic loss equation for far-field separations:

$$L = 20 (\log f + \log d) + 37 \tag{5-1}$$

where:

L = free-space transmission loss (for line-of-sight transmission) (dB).

f = frequency of signal (MHz).

d = distance in statute miles between the potentially interfering transmitter and its victim receiver.

Equation (5-1) assumes isotropic antennas, hence the gains of both the transmitting and receiving systems are assumed to be unity with respect to an isotrope.

When refinements as to the actual propagation losses are required, several conditions and types of transmission must be considered. All of the losses incurred from the many propagation factors simply reduce the strength of the potentially interfering signal even further than that provided by the free-space losses.

5.1.4 Equipment Susceptibility

a. General. Any equipment or device capable of responding to electromagnetic fields or to electrical signals must be considered a suspect for susceptibility to emissions. Whereas the previous sections described the generation and transmission of signals, this section deals with the receipt of, and reaction to, these signals by various equipments.

In the study of equipment sensitivity, two broad categories can be established: equipments that are frequency selective, and those that respond over a wide frequency band. The former category includes primarily, communication, radar, and other type radio receivers. Examples of devices that respond over a wide range of frequencies are meters, indicator lights, control circuitry, wideband amplifiers, and relays.

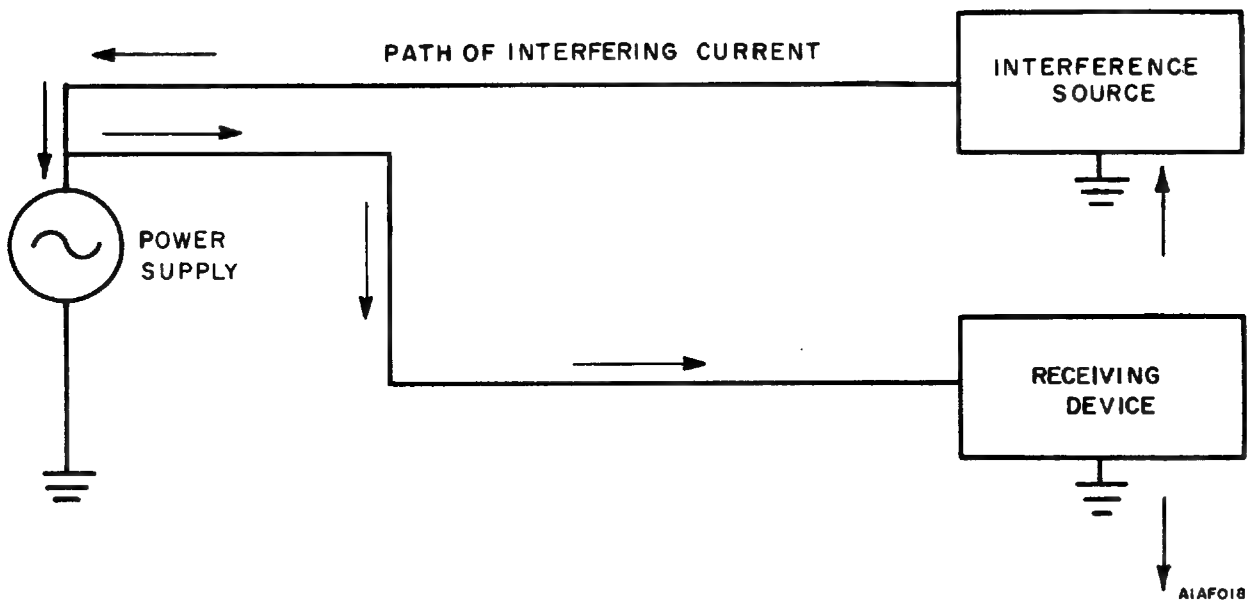


Figure 5 - 4. Interference Coupling by Conduction

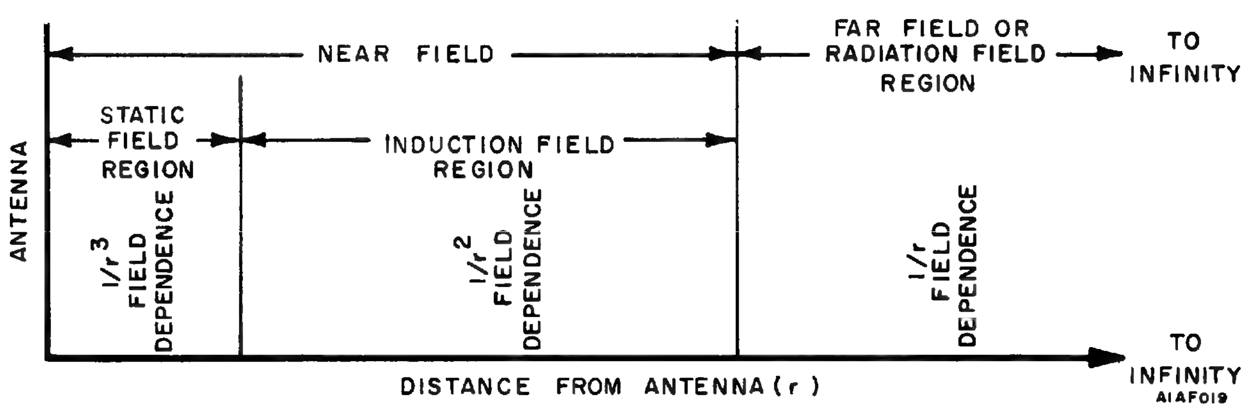


Figure 5 - 5. Electric Field Regions of a Radiating Element

It should be noted that susceptibility is not an absolute, definitive property of a piece of equipment or device, but must be related to the particular type of emission and its mode of entry into the equipment. The establishment of susceptibility criteria or limits for various equipments is purely subjective, and is based on the decision as to what constitutes an unacceptable degradation of output or performance. In voice communications, for example, a signal-to-noise ratio of zero to 6 dB may be regarded as just acceptable, ratios up to 20 dB as satisfactory, and above 20 dB as excellent.

The specification of susceptibility of an individual equipment may vary when a distinction is made between its function as an isolated equipment and its use as part of a system or installation. In the latter case, performance specifications and the degree to which the system or installation depends on its individual equipments will influence the equipment susceptibility level. System or installation performance will then be dependent upon its most susceptible equipment.

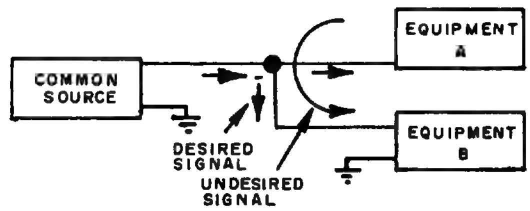
b. Entry Mechanisms. In the previous section it was stated that undesired signals are transmitted by conduction or radiation, or both. Such signals may gain entry into equipment via the various cables, connectors, through the grounding system, by sensors connected to the equipment or by direct irradiation of the equipment by an electromagnetic field.

Basically, there are two modes of entry of an undesired signal: the normal, or differential mode, in which the unwanted signal is introduced into the desired signal; channel through the same path as that of the desired signal, and the common-mode, in which the unwanted signal is introduced into the desired signal channel from a source having at least one terminal which is part of the desired signal channel. That is, the undesired current path is only partly common with the signal current path, usually through the chassis or ground system. Figure 5-6 depicts examples of the entry mechanisms. In figure 5-6A unwanted current is conducted from the source, located in equipment A, to the receiving unit, equipment B, via common input leads. If the common source is supplying the desired signal to the two equipments, then this situation can be classified as differential mode; if the common source is a power supply, then entry of the undesired current would not be over the normal signal path, and the coupling would be classified as common-mode. A second differential-mode case is shown in figure 5-6B in which entry occurs via either magnetic or capacitive coupling between signal leads and an adjacent power or transmission line. In this case, transmission of the undesired signal is by radiation. Common-mode coupling in which the common path is the ground return, is shown in figure 5-6C. Two sources supplying their individual loads via common ground returns are also shown in figure 5-6C. The circuit has been redrawn to include the impedance of the ground path. As a result of the finite ground impedance shared by the two signal paths, coupling between the paths takes place. This type of coupling is quite common in equipment design and may be minimized by using various techniques to avoid such common paths, e.g., use of separate grounds, heavy ground fuses, etc. Design details to avoid common-mode coupling are given in Chapter 6. Direct radiation entry is illustrated in figure 5-6D. Antennas are, of course, a major point of intrusion in radio receivers. Radiation which gains entry into receivers via their associated antennas is discussed below and from an inter-system viewpoint in the section covering prediction and analytical techniques. Radiation may gain direct entry into equipments through ventilation holes, meter and other panel openings, through inadequate shields, or may cause currents to be induced on equipment cabling, connectors and other wiring. The latter cases usually originate within a system or equipment and may be regarded as intrasystem coupling.

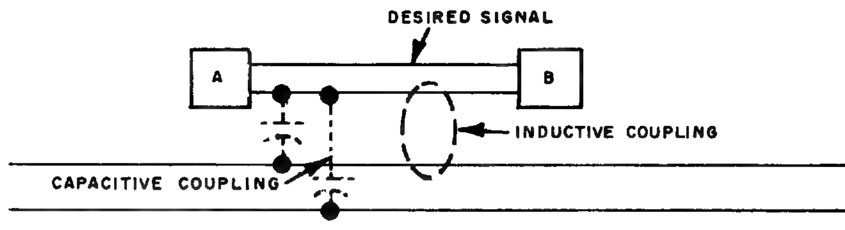
c. Equipment Susceptibility Characteristics.

(1) Wideband Equipment. The term, wideband equipment, refers to all electrical and electronic devices other than those which are tunable to or fixed at a selected band of frequencies. In general, because of the complexity of types, arrangements, and operational characteristics of equipment, and because of the many types of interference causing signals, entry modes and interactions. the susceptibility characteristics of this equipment category have not been completely documented, or standardized. Susceptibility of individual equipments used for specific requirements is best determined by test, either by simulation of interference signals or under actual operating conditions. Requirements and test methods are outlined in MIL-STD-461 and -462, respectively. A brief qualitative discussion of some susceptibility characteristics follows.

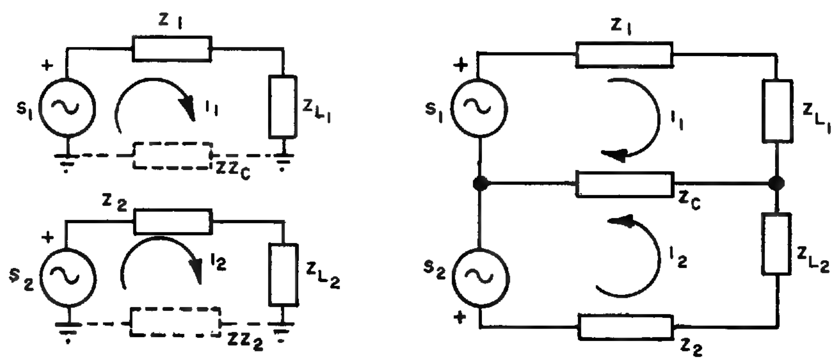
(A) DIFFERENTIAL MODE



(B) DIFFERENTIAL MODE



(C) COMMON MODE



(D) DIRECT RADIATION

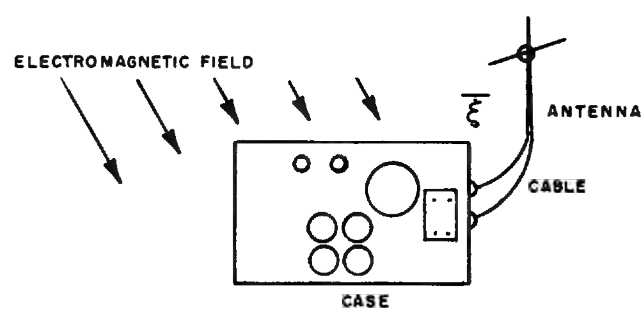


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Figure 5 - 6. Signal Entry Paths

(a) Digital Computers. Since operation of digital computers depends upon pulses and levels of fixed amplitudes occurring at correct predetermined times they are particularly susceptible to pulse-modulated high frequency radar signals. Experimental investigations have demonstrated false switching in flip-flops and logic gates, deteriorated legitimate signals and erroneous outputs in which the rise-time, as well as the amplitude, of the interfering pulse were important. Ordinarily, basic solid state circuitry is ostensibly more susceptible to interference emissions than its vacuum tube counterpart. This may be traced to the lower operating signal levels of the solid-state computer with associated lower signal-to-interference ratios.

(b) Control and Indicating Devices. This equipment category frequently includes low-level, high-impedance input-type amplifiers that are used in the processing of sensor signals, control of electromechanical devices, display of transducer sampling, and many other functions. Examples are servo amplifiers, DC amplifiers, indicators and sensitive test equipment Since this type of equipment frequently operates by modulation of the 60 Hz and 400 Hz power frequencies they are particularly susceptible to power line transients and stray coupling to wiring, transformers, etc., operating at power frequencies. Because they operate at relatively low signal levels, amplifiers of this type are troubled by common-mode coupling at their input terminals. Rectification of high-frequency signals by non-linear circuit elements can cause saturation or de-sensitization of gain characteristics, or cause parasitic oscillations.

(c) Displays. Cathode-ray tube type displays are susceptible to emission from radars, communication transmissions, ignition systems, and other equipments. The main effect is the disruption of the visual information presented to the equipment operator. Cathode-ray tubes are susceptible to stray magnetic fields which act to deflect the electron beam. The circuits which process the video, or information signal, and those that generate the required sweeps, are subject to power line and common-mode coupling as outlined in the previous section. Interference in sweep circuits is characterized by distortion of the display (by causing the sweep to be non-linear), while undesired responses in the video sections may appear as intensity modulations.

Nixie tube, solid-state and other alpha-numerical type displays generally use digital logic gating to form the read-out and are, hence, subject to the same responses as digital computers, i.e. false switching and loss of synchronism leading to erroneous readouts.

(2) Frequency Selective Equipment. Frequency selective or narrowband equipment includes all equipment types which are tunable over, or fixed to operate at, a selected range of frequencies. Receivers of all types, having the reception of electromagnetic energy as their prime function, form the major class of devices in this category. Since they are deliberately designed, in many cases, to optimize their sensitivity, and because of their frequency band restrictions, receiving devices are subject to more numerous, more complex interference situations than other equipment types. Examples of radar interference are shown in figure 5-7. Tables 5-1 and 5-2 list interference modulation characteristics on radar and communication receivers, respectively.

Receivers may be classified into two major design types: the heterodyne and the crystal video type receiver, the designs of which are documented in the literature.

5.2 BASIC RADHAZ CONSIDERATIONS

5.2.1 General

Whereas the previous discussion concerned itself with the interaction of electromagnetic energy with communications-electronics equipments from the standpoint of performance degradation, this section deals with the basic effects of electromagnetic radiated energy on personnel, flammable mixtures, ordnance, and electronic hardware from a hazard standpoint.

Refer to NAVELEXINST 5100.4 for information on hazards and NAVFACINST 8020.3 regarding site approvals for transmitter and antenna installations.

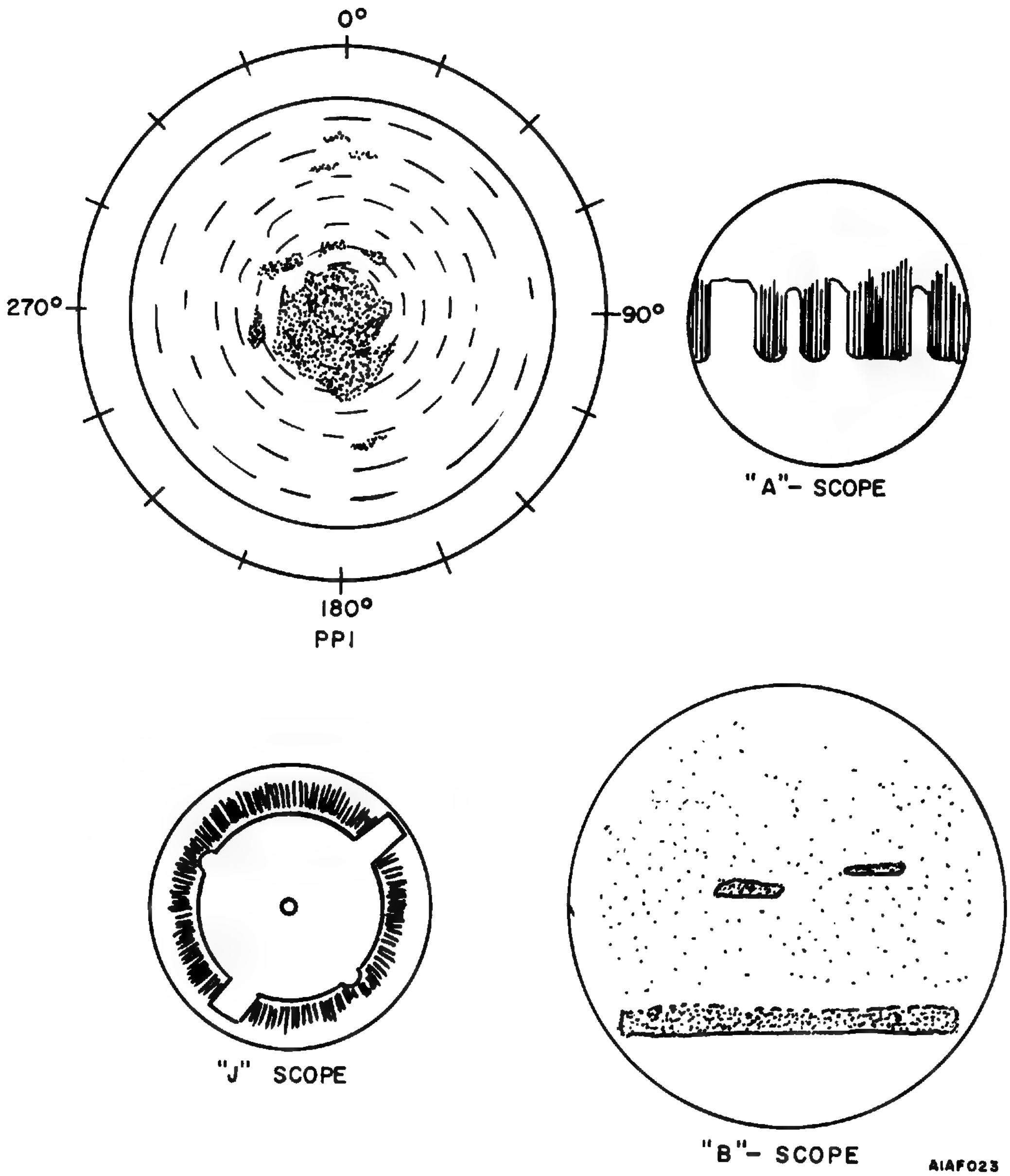


Figure 5-7. Interference Patterns on Radar Scopes

Table 5-1. Interference Modulation Characteristics On Radar Scopes

SCOPE TYPE	BROADBAND		NARROWBAND	
	PERIODIC	RANDOM	UNMODULATED	MODULATED
PPI	Fixed or moving dot or spiral pattern.	Random dot pattern or general increase in noise level (pattern cannot be fixed by adjustment of Pulse Repetition Frequency (PRF) or antenna scan rate)	Variation in the intensity of display.	Very rapidly changing dark and light scope patterns.
A	One or more fixed or moving pulses (running rabbits). Interfering PRF can be adjusted for one fixed (or slowly moving) pulse when the scope is adjusted for maximum range.	Random positioned pulses, or general increase in noise level (grass). Sometimes a reduction in MVS.	Change in noise level generally a reduction. The MVS detection capability will be reduced.	Rapid variations in the noise level with extraneous noise on scope.

Table 5-2. Interference Modulation Characteristics at Communications Receiver Audio Output

RECEIVER AUDIBLE OUTPUT	CHARACTER OF INTERFERENCE	POSSIBLE SOURCE OR MECHANISM
Reduced noise level (or steady tone with BFO operating)	Carrier (only)	Cochannel, spurious intermodulation
Pulsed variation in noise level (or pulsed tone with BFO operating)	Unwanted CW or digital transmission	Adjacent channel, cochannel, spurious, intermodulation, cross modulation
Pulsed variation in noise level (two pulsed tones with BFO operating)	Unwanted RADTT (FSK) transmission	Adjacent channel, cochannel, spurious, intermodulation, cross modulation
Pulsed tone	Unwanted MCW transmission	Adjacent channel, cochannel, spurious, intermodulation, cross modulation
Added normal or distorted voice	Unwanted voice transmission	Adjacent channel, cochannel, spurious, intermodulation, cross modulation
Whistling or squealing	Unwanted transmission or intermediate frequency oscillation	Adjacent channel, cochannel, spurious, intermodulation, cross modulation, parasitic and IF oscillation
Rapid variation in noise level (or several pulsed tones with BFO operating)	Unwanted facsimile transmission	Adjacent channel, cochannel, spurious, intermodulation, cross modulation
Steady tone or whining	High rate periodic pulses	Radar, rotating machines
Buzzing	Medium rate periodic pulses	Buzzers, vibrators
Popping	Low rate periodic pulses	Ignition systems, magnetos
Frying	High rate random pulses	Electric arcs, continuously arcing contacts
Sputtering	High rate random pulses	Arc welders, arc lamps, diathermy
Clicking	Low rate random pulses	Code machines, electric calculating machines, mercury arc rectifiers, relays, switches, teletypewriters, thermostatic controls, electric typewriters
Crackling		Static or corona discharges
Sharp crackle		Ambient noise

5.2.2 Hazards to Personnel

The human body is composed of various tissues which may be considered as a transmission medium exhibiting the characteristics of a complex dielectric material.

At certain frequencies, the thickness of the skin and fat tissue layers may act as a quarter-wave matching transformer to match the impedance of air to the input impedance of the deep tissues, resulting in a transfer of power into the deep tissues, with very little loss and little heating of the skin and fat tissue layers near the body surface.

The penetration of energy into the body and its absorption (loss of energy), and reflection will depend not only upon the physical dimensions and dielectric constant of the tissues, but also upon the frequency (wavelength) of the electromagnetic radiation.

When electromagnetic energy is absorbed into tissues of the body, heat is produced in the tissues. If the organism cannot dissipate this heat energy as fast as it is produced, the internal temperature of the body will rise. This may result in damage to the tissue and, if the rise is sufficiently high, in death of the organism. The body's ability to dissipate heat successfully depends upon many related factors, such as environmental air circulation rate, humidity, air temperature, body metabolic rate, clothing, power density of the radiation field, amount of energy absorbed, and duration of exposure (time).

When the body is irradiated by energy in the form of a beam originating from a point source, the total body surface is usually not exposed. Only the portion facing the source is exposed, provided that no reflections of energy occur from nearby reflecting surfaces to cause complete irradiation of the body. The temperature elevation produced by the exposure obviously depends on the ratio of the body surface irradiated to the total body surface. The larger the area exposed, the higher the temperature rise, and the greater the hazard. The increase in body temperature to the tolerance threshold (the point at which biological effects begin to occur) may possibly be delayed if the exposure occurs in an environment of low ambient temperature and adequate air circulation. It is interesting to note that sedatives and tranquilizers interfere with the body's ability to regulate temperature and lose heat.

Certain organs of the body are considered to be more susceptible than others to the effects of electromagnetic radiation. Organs such as the lungs, the eyes, the testicles, the gall bladder. the urinary bladder, and portions of the gastrointestinal tract are not cooled by an abundant flow of blood through the vascular system. Therefore, these organs are more likely to be damaged by heat resulting from excessive exposure to radiation. Of the organs just mentioned, presently available information and experience indicate that the eyes and testicles are the most vulnerable to microwave radiation.

a. Relationship of Physical Size to Wavelength. When considering the biological effects produced by electromagnetic radiation, the wavelength (frequency) of the energy and its relationship to the physical dimensions of object exposed to radiation become important factors. It has been determined that for any significant effect to occur, the physical size of the object must be the equivalent of at least a tenth of a wavelength at the frequency of radiation.

A comparison of frequency, propagation wavelength, and the number of physical wavelengths represented by a man 1.7 meters (5 ft. 7 in.) tall is given in table 5-3.

From the values given in the table, it can be seen that the man chosen for the example is 1.7 wavelengths tall at 300 MHz, 17 wavelengths tall at 3000 MHz, and 56.6 wavelengths tall at 10,000 MHz. As the frequency of radiation increases, the wavelength decreases, and the man's height represents an increasingly greater number of electrical wavelengths. As the frequency is decreased, the wavelength increases, and the man becomes a less significant object in the radiation field. Thus, at 30 MHz the man's height (1.7 meters) represents 0.17 wavelength, and at frequencies below 17.7 MHz it represents less than 0.1 wavelength.

Table 5-3. Comparison Of Frequency, Wavelength, And Equivalent Number Of Wavelengths Of Man 1.7 Meters Tall

FREQUENCY (MHz)	WAVELENGTH METERS	WAVELENGTH cm	EQUIVALENT NUMBER OF WAVELENGTHS
3	100	100,000	0.017
30	10	10,000	0.17
300	1	100	1.7
3000	0.1	10	17.0
10.000	0.03	3	56.6

From this discussion it can be seen that the man chosen for the example, whose physical height is 1.7 meters and represents a tenth of a wavelength at 17.7 MHz, is an increasingly larger object for all frequencies above 17.7 MHz. Neglecting other physical measurements of the body, it is seen that if the man is considered to be a vertical receiving antenna, his electrical length (height) depends upon the frequency of radiation. Also, as the radiation frequency is increased and the wavelength becomes progressively shorter, the dimensions of parts and appendages of the body in themselves become increasingly significant in terms of the number of equivalent electrical wavelengths.

Practically speaking, the human body is a three-dimensional mass having width and depth, as well as height. Therefore, when a man stands erect in an electromagnetic field, he represents an object which not only has a height dimension, but also has width and depth dimensions that can be expressed in terms of wavelength. Again comparing the physical characteristics of the human body to those of a broadband receiving antenna, when the body is oriented so that any of these major body dimensions is parallel to the plane of polarization of the electromagnetic energy, the effects produced are likely to be more pronounced than when the body is oriented to other positions.

b. Summary of Thermal Biological Effects. The knowledge gained from laboratory experience concerning the effects of radiation within the range of frequencies from 150 to 10,000 MHz (200 to 3 cm wavelength) are outlined in table 5-4 and can be summarized as follows:

(1) The percentage of absorbed biologically effective energy approaches 40 percent of the incident energy for frequencies below 1000 MHz (30 cm) and for frequencies above 3000 MHz (10 cm).

(2) The percentage of absorbed biologically effective energy is between 20 and 100 percent of the incident energy for frequencies between approximately 1000 and 3000 MHz (30 to 10 cm wavelength).

(3) The sensory elements of the body are located primarily in the skin tissues. For this reason particular caution must be exercised in the presence of radiation frequencies below 1000 MHz because the resultant heating will not be detected as readily by the human sensory system. Radiation at frequencies below 1000 MHz causes heat to be developed primarily in the deep tissues as a result of the penetration of the energy. The energy absorbed in body tissues may be as high as 40 percent of the incident arriving at the body surface.

Table 5-4. Resumé of Biological Effects of Microwaves

FREQUENCY (MHz)	WAVELENGTH (cm)	SITE OF MAJOR TISSUE EFFECTS	MAJOR BIOLOGICAL EFFECTS
Less than 150	Above 200	Under investigation	
150 - 3,300	200 - 10	Internal body organs	Damage to internal organ from overheating
		Lens of the eye	Lens of the eye particularly susceptible and tissue
3,300 - 10,000	10 - 3	Top layers of the skin,lens of eye	Skin heating with the sensation of warmth
Above 10,000	Less than 3	Skin	Skin surface acts as reflector or absorber with heating effect

(4) Frequencies greater than approximately 3000 MHz cause heating of tissues in much the same manner as does infrared radiation or direct sunlight; therefore, the sensory reaction of the skin should normally provide adequate warning of the presence of electromagnetic radiation. In general. the depth of energy penetration decreases rapidly with an increase in radiation frequency, and absorption occurs almost completely in the surface of the body where skin tissues and the sensory elements are located. Also, reflection of energy at the surface of the skin occurs at the higher frequencies. Thus, the percentage of energy absorbed may approach 40 percent of the energy incident on the body surface, with a greater portion of energy being reflected.

(5) Radiation at frequencies between 1000 and 3000 MHz is subject to varying degrees of penetration and is absorbed in both surface tissues and the deeper tissues, depending upon the characteristics of the tissues themselves (thickness, dielectric constant, and conductivity) and the frequency of radiation. The percentage of incident energy absorbed varies from approximately 20 to 100 percent because of tissue factors governing impedance values, which range from complete mismatch to a near perfect match to the incident energy. Hence, this frequency range is considered the most hazardous.

c. EMR Burns and Other Hazards. Electronic equipment radiating RF energy may cause a voltage to be induced in metallic objects which approach resonance or are resonant to the transmitted fundamental frequency or one of its harmonic frequencies. The proximity and position of the radiating antenna and the directivity and polarization of the beam relative to the conductive object will govern the amount of induced voltage present. Such induced voltages may cause shock or RF burns to personnel or may produce open sparks when contact between conductive objects is made or broken. For example, tests indicate that high RF voltages are induced in metal tools, common lead pencils, etc., near the center of the radar beam where the radiated power density is the highest, and that the resulting discharge may cause an arc of sufficient intensity to ignite gasoline vapors. It is also possible that light metallic objects in the beam may become heated sufficiently to ignite flammable vapors.

Aboard ships, voltages may be induced in standing rigging, cables, parts of the superstructure, and deck loads. Measurements aboard various ships have shown that voltages of sufficient amplitudes to cause severe burns to personnel can be induced into cargo handling equipments by radiation from HF transmitting antennas.

In addition, the involuntary reaction of personnel to nonlethal EMR shock is extremely dangerous when a person is working in close quarters or in elevated locations since such reflex action can result in falls or bodily injury due to striking an object.

d. Athermal Effects. Much of the early work in the field of biological hazards concluded that the only significant biological effect of EMR was thermal in nature. In recent years however, the possibility of non-thermal effects have been discussed, some of which have been shown to be dependent on peak powers whose average value is not great enough to produce heating. Frequency dependence with no heating, has also characterized many of the observed effects. While the full significance of these effects to humans is still under investigation, an awareness of their existence should be considered.

e. X-Radiation Effects. Ionization is involved in the production of biological effects of X-radiation. All X-rays except those of very low photon energy will penetrate human tissue and form positive and negative ions. Depending upon the dosage, these ions may cause tissue damage of either a temporary or permanent nature. Unless the dosage is extremely high, there will be no noticeable effects for days or weeks or, in some cases. years after the exposure. This delay in the effect is no doubt the most important reason for cases of overdoses of X-rays, since the damage has been done long before the symptoms begin. The effects presented herein are those restricted to the incidental X-radiation from electronic equipments. See NAVMAT P-5100 and NAVMED P-5055 for other X-radiation effects.

f. Other Effects.

(1) Laser Radiation. Research encompassing that portion of the electromagnetic spectrum which includes the infrared and wavelengths in the visible region has resulted in the use of these wavelengths in devices which have military application. The laser, for example, is coming into more widespread use in such devices as rangefinders, survey transits, tracking instruments and communications equipment thus increasing the probability of personnel exposure to laser radiation.

Some of the known biological effects of exposure to these wavelengths are described below:

o Infrared. Infrared energy, using conventional sources, has been used in the military for many years in such areas as tactical communications, beacons, surveillance, missile guidance, tracking, and many other applications. Only active infrared systems, in which a source is used to generate energy which is then radiated in some manner, are potentially hazardous. These systems generally use filters to remove any visible radiation. A characteristic of the infrared portion of the electromagnetic spectrum permits the waves to be readily absorbed and the energy converted into heat. Infrared radiation does not exist as heat waves. It behaves as do radio or light waves and is transmitted in the same manner through air or vacuum. Infrared radiation can be refracted and reflected according to the laws of optics, since infrared and visible light are of the same nature. The fact that infrared radiation is readily converted into thermal energy when it strikes an object distinguishes it from other types of electromagnetic radiation. The human eye is susceptible to damage by infrared energy, since the energy may cause the development of cataracts or opacities similar to the damage caused by radio-frequency and ionizing radiations described previously. Infrared is invisible and it is therefore possible that personnel may interrupt an infrared beam (from an active system) without being aware of the fact.

o Visible Wavelengths and Ultraviolet. See figure 5-8. Potential radiation hazards from both the visible wavelengths and the ultraviolet stem mainly from their use in equipments using laser energy sources, although ultraviolet emissions have been reported from cathode-ray tube and PPI equipment. Infrared wavelengths are also generated in CO_2 type lasers, as well as by the conventional sources mentioned above. The effects of laser radiations are essentially the same as light generated by more conventional ultraviolet, infrared and visible light sources. The unique biological implications attributed to laser radiation are generally those resulting from the very high intensities and monochromaticity of laser light. Such sources differ from conventional light emitters primarily in their ability to attain highly coherent light (in phase). The increased directional intensity of the light generated by a laser results in concentrated light beam intensities at considerable distances. Laser radiation should not be confused with ionizing radiation (such as X and gamma rays) although very high power or energy densities have been known to produce ionization in air and other materials. The biological effects of the laser beam are essentially those of visible, ultraviolet, or infrared energy upon tissues. However, the intensity of the light is of magnitudes that could previously be approached only by the sun, nuclear weapons, burning magnesium, or arc lights. This is one of the important properties that makes lasers potentially hazardous.

A laser beam striking tissue will be reflected, transmitted, and absorbed. The degree to which each of these reactions occurs depends upon various properties of the tissue involved. Absorption is selective, as in the case of visible light; darker materials such as melanin or other pigmented tissue absorb more energy.

Skin effects may vary from mild reddening to blistering and charring, depending upon the amount of energy transferred.

The effect upon the retina may be a temporary reaction or it may be more severe with permanent changes. The mildest observable reaction may be simple reddening: as the energy is increased, lesions may occur which progress in severity with hemorrhaging and additional tissue reaction around the lesion. Very high energies will cause gases to form, which may disrupt the retina and may alter the physical structure of the eye. Portions of the eye other than the retina may be selectively injured, depending upon the region where the greatest absorption of the specific wavelength of the laser energy occurs and the relative sensitivity of tissue affected.

Infrared light produces heat with its characteristic effect on tissue and the lens of the eye. Some residual energy may reach the retina. Ultraviolet light can produce symptoms similar to those observed in arc welders. It may cause severe acute inflammation of the eye and conjunctiva, and usually does not reach the retina. Light in the far infrared, such as the 10 micron wavelength from the carbon dioxide lasers, is absorbed by the cornea and conjunctiva and may cause severe pain and destructive effects.

o Most higher energy X-rays and gamma rays pass completely through the eye.

o For short ultraviolet, absorption occurs principally at the cornea.

o Long ultraviolet and visible light is refracted at the cornea and lens and absorbed at the retina.

o Near infrared energy is absorbed in the ocular media and at the retina; near infrared rays are refracted.

o Far infrared absorption is localized at the cornea.

o Microwave radiation is transmitted through the eye, although a large percentage may be absorbed.

Ultraviolet light can also cause severe burns, chromosome breaks, affect cell division, metabolism, and other body processes.

5.2.3 Hazards to Fuels

Potential hazards to fuel vapors are presented by sparks (or arcs) caused by EMR induced voltages. The ability of an arc to ignite a vapor-air mixture depends upon: properties of fuels which determine their susceptibility to or ease of ignition are the flash point, flammability limits, vapor pressure, and presence of a flammable fuel-air mixture; energy contained in and the duration of the arc; and the distance or gap across which the arc occurs.

a. Fuel Types. For the purpose of this manual, the following terminologies are used:

(1) Aviation gasoline shall mean all gasoline grades of fuel for reciprocating engine-powered aircraft of whatever octane rating having the general characteristics as described herein.

(2) JET A and JET A-1 shall mean kerosene grades of fuel for turbine engine-powered aircraft by whatever trade name or designation having the general characteristics as described. JET A has a -40° F freezing point (maximum), JET A-1 incorporates special low temperature characteristics for certain operations having a -58° F freezing point (maximum). JP-5 and JP-6 are grades of JET A fuel as used by the U. S. military.

(3) JET B shall mean all blends of gasoline and kerosene grades of fuel for turbine engine-powered aircraft by whatever trade name or designation having the general characteristics as described herein. JET B is a relatively wide boiling range volatile distillate having a -60° F freezing point (maximum). JP-4 is one grade of JET B fuel as used by the U. S. military.

b. Energy and Duration of the Arc. The amount of energy and time duration required in a spark to ignite a flammable gasoline-air mixture is still under investigation. Early experiments at the Naval Research Laboratory were primarily based on the use of DC type sparks. Also, considerable difficulty has been experienced in the laboratory in obtaining gasoline vapor-air mixtures which can be precisely controlled and readily duplicated. Therefore, propane has been used in lieu of gasoline because its ignition characteristics are similar to those of gasoline and it is easier to meter in the proper proportions with air to provide the control necessary for laboratory experimentation. It has been determined experimentally that 2.5×10^{-4} watt-seconds of energy is required in a spark of 0.01 to 1.0 microsecond duration across a plain electrode gap to ignite a propane-air mixture. The minimum quenching distance (see the following paragraph) for the electrodes used with propane was found to be 1.75 mm (0.0689 in.). The amount of DC voltage required to break down an air-gap of this dimension is approximately 2500 volts; the amount of RF voltage required to break down a similar gap is unknown but it is believed, until proven otherwise, to be approximately the same as the DC voltage value. Additional quantitative criteria are presented in paragraph 5.3.

c. Arc Gap Distance. The minimum gap distance across which the spark must discharge will have an effect upon the possible ignition of a flammable mixture. If the gap distance is smaller than a minimum value, the spark (flame) occurring at the gap will be quenched through the removal of heat (energy) by the gap electrodes themselves, therefore, a flammable mixture will not be ignited. However. if the voltage gradient is large and the gap distance is above the minimum quenching distance, the spark (flame) will have sufficient energy (heat) to ignite a flammable mixture. The minimum quenching distance is dependent upon the size of the electrodes, the nature of the dielectric (in this case the density of the vapor-air mixture), the ambient temperature and pressure, and, to some extent, the characteristics of the electrode material(s). The voltage required to break down the gap

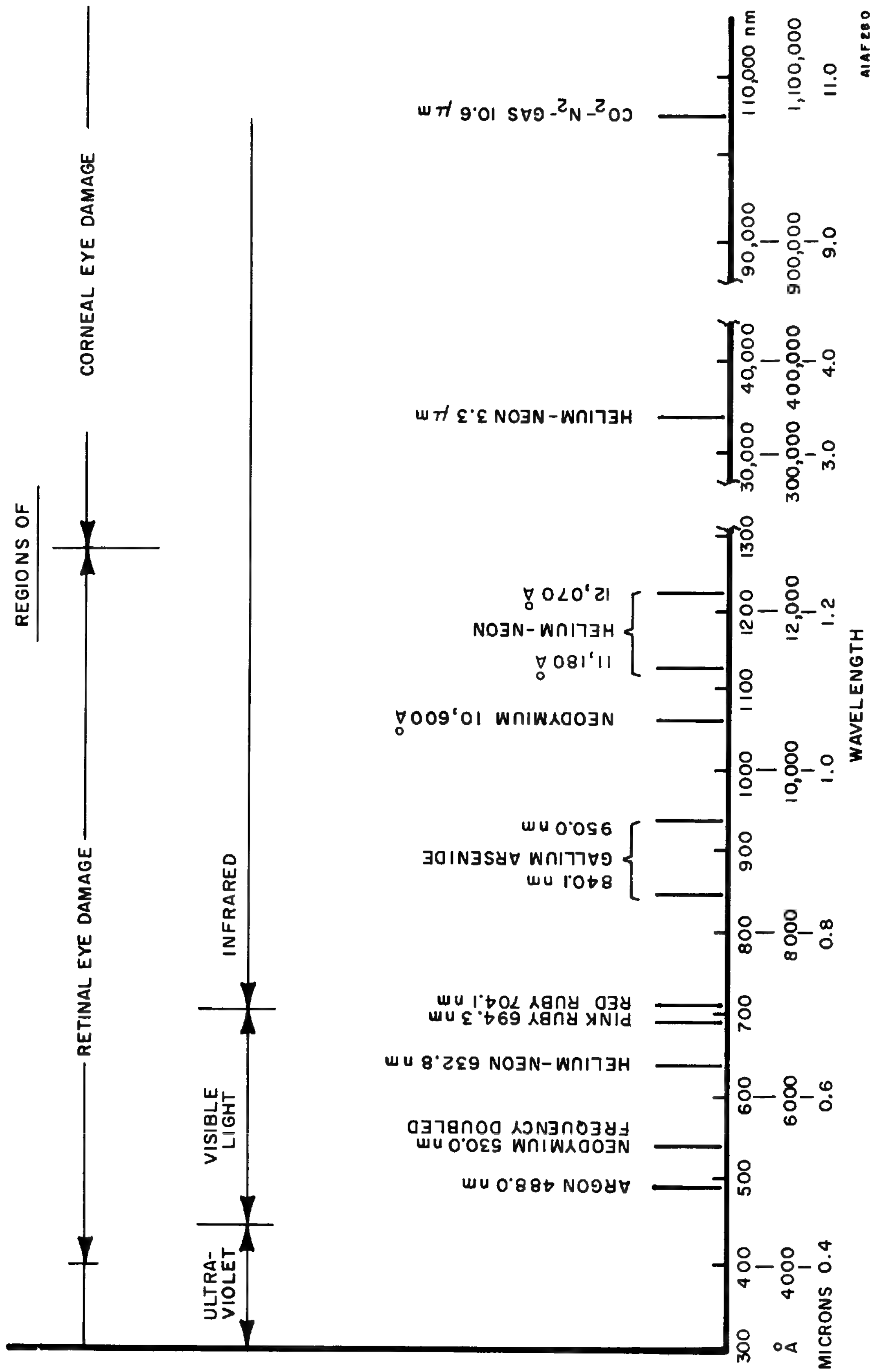


Figure 5 - 8. Laser Wavelength Chart

depends upon the density of the dielectric and the electrode spacing, assuming that there is no ionization between the electrodes which could cause a breakdown at a lower voltage. The dielectric strength of the atmosphere between the gap electrodes increases with increasing density; therefore, the greater the density of the vapor-air mixture, the greater the voltage gradient required to break down a fixed gap. Also, once the breakdown occurs, the gap distance may be increased without extinguishing the spark. This increase in gap distance is possible because of the heating of the electrodes by the current flow, which is concentrated within a decreasing area on the electrodes as they separate. This, in turn, causes the emission of electrons due to the rise in temperature in the smaller conducting area of the electrode. Sparking will continue until the gap dimension has increased to a point where the gap resistance no longer permits sufficient current flow to maintain electron emission temperature at the surface of the electrodes. Thus, the ionization between the electrodes ceases because of decreased electron current flow, and the spark is extinguished.

It should be noted that when a parallel-resonant tuned circuit is placed across the electrodes of a gap in an electromagnetic field, sparks are more easily produced because of a resonant rise in voltage across the tuned circuit, which is tuned to the applied frequency. Therefore, it is conceivable that at some frequency the bonding or grounding wire used to dissipate static electricity during refueling operations may actually be resonant at the transmitted frequency (or a harmonic thereof). Note that a half-wavelength in free space for frequencies of 3 MHz and 30 MHz is 164 feet and 16.4 feet, respectively, while a half-wavelength at frequencies of 300 MHz and 3000 MHz is only 19.68 inches and 1.97 inches, respectively. Although the parts connected by the bonding or grounding wire are at the same static or DC potential, these parts are connected by a length of wire, which may represent a relatively high impedance to radio frequencies. Thus. these parts are in effect virtual electrodes of a spark gap, and when an electromagnetic field is present a relatively high RF voltage may be developed between them. Thus, if the gap dimension is sufficiently small, a spark may be produced by breakdown of the vapor-air dielectric between the electrodes of the gap, and ignition of flammable vapors can occur.

d. Summary. The three requirements for the inadvertent ignition of fuel by RF energy are:

(1) The presence of a proper air-fuel mixture.

(2) A correctly-sized gap across which the spark occurs.

(3) Sufficient spark energy and time duration.

Based on the necessity for the simultaneous occurrence of all three conditions, it may be stated that the statistical probability of inadvertent ignition is small.

Handling of aviation gasoline under normal operating conditions does not produce a flammable atmosphere except close to aircraft fuel vents, open fuel inlets during over-the-wing fueling, or close to spilled gasoline.

Note, however, that the vapor densities of aviation fuels are such that released vapors, particularly under calm wind conditions, may travel considerable distances along the ground and collect in depressions where they may not readily dissipate. The concentration of fuel vapors in the area surrounding the aircraft depends upon wind velocity and rate of fueling. Fuel spillage, therefore, represents the greatest hazard.

Although energy from radar or other RF generating equipment represents a potential source of ignition, the greatest hazards to fuels are probably from lightning and the accumulation of static electricity. Protection criteria for these sources is given in NAVAIR 06-5-502, T.O. 31-10-24, NAVSHIPS 0900-005-8000, and in National Fire Protection Association (NFPA) Standard No. 407.

5.2.4 Hazards to Ordnance

a. General. Hazards to ordnance from electromagnetic energy stem from the use of sensitive, electrically-initiated explosive elements, known as electroexplosive devices (EED's), which can be activated by electromagnetic energy, and from the susceptibility characteristics of the equipment used to fire the EED. Hazards include both inadvertent initiation of the EED and degradation of the intended performance characteristics (although, strictly speaking, this is not a direct hazard). Refer to NAVORD OP-3565/NAVAIR 16-1-529.

b. Coupling Mechanisms. RF energy coupling to an EED occurs through the basic mechanisms described in paragraph 5.1.2: by conduction, by radiation, or through a combination of these.

The exterior of a weapon may be energized either by incident fields from external sources or by direct coupling from its own internal sources. Whatever the source, the surface distribution of current and charge may exhibit stationary patterns depending on the method of excitation, the wavelength of the excitation current, and the geometry of the weapon. These patterns are,in general,very complicated.

In electrical and mechanical form, the receiving antennas that contribute to the problem in actual weapons systems are not necessarily recognizable as antennas. They may take the forms of umbilical cables, access doors and hatches, or discontinuities in weapon skins and shields, but they nevertheless function as linear antennas, current loops, or cavity and slot aperture antennas.

Some of the ways in which umbilical cables, apertures, and discontinuities in the weapon skin can function as receiving antennas for RF energy are shown in figure 5-9. Panel (a) of the figure illustrates an umbilical cable as the receiving antenna (vertical or loop) and an internal loop antenna consisting of an EED and its associated wiring. External cables can act as effective receiving antennas when exposed to RF energy, permitting the transfer of RF currents into the weapon, and direct or inductive coupling to an EED bridge wire can result. This type of receiving antenna can be an effective receiver at communications frequencies, depending on the length of the external cables and their connections.

Panels (b) and (c) of the figure illustrate apertures in a weapon skin acting as receiving antennas. These apertures are effective receiving antennas at frequencies at which their dimensions approach one wavelength. The amount of RF energy transferred into the cavity becomes more pronounced when the dimensions of the cavity approach one wavelength. This occurs most often at radar frequencies. The RF energy is coupled from the fields developed in the cavity to the bridge wire by capacitive and inductive means.

Panel (d) illustrates energy transfer occurring as a result of an RF arc. When connection is either made or broken between any two weapon elements having different RF potentials (e.g., connectors between weapon and launcher or between weapon and test equipment), arcs occur which can produce large amounts of energy in the DC and audio frequency ranges. If RF arcs occur in the firing circuits and there is a complete DC circuit, this energy can be delivered to an EED even if the EED is protected by a low-pass filter.

Under any of the conditions illustrated in figure 5-9 the energy transfer can be increased by personnel in proximity to the weapon. The human body displays receiving antenna characteristics, and the addition of personnel can increase the efficiency of the transfer path of RF energy to the susceptible portions of the weapon.

c. Susceptibility Characteristics. Electroexplosive devices (EED's) are used in virtually every major piece of naval ordnance. They take a large number of different configurations and have many applications (see table 5-5), but their essential nature remains the same.

By accepted definition, an EED is an electric initiator or other component in which electrical energy is used to cause initiation of explosives contained therein. Inadvertent initiation of an EED may occur as a result of RF energy unintentionally conducted to the EED. This is the basic problem. The designer is reminded of the Navy requirement that an EED should be used only when the system requirements cannot be met by other means which are equally effective.

A schematic diagram of the most commonly used type of EED (hot bridge wire EED) is shown in figure 5-10A. An EED of this type is normally initiated by passing a direct current through the bridge wire, heating it, and thus initiating the primary explosive charge surrounding it. The primary charge sets off the booster charge, which in turn sets off the main charge. Although some types of EED's are initiated by arcing or shock waves, heat is the most commonly used method of initiation. Radio frequency energy can initiate or dud an EED in the same manner, i.e., by resistance heating of the bridge wire.

Table 5-5. Typical Application of EED

Rocket Ordnance	
	Ignition systems for solid and liquid propellent
	Explosive actuation of battery systems
	Explosive mechanical detents
	Detonators for warheads
Guided Missiles	
	Ignition systems for solid and liquid propellents
	Explosive actuation of relays, switches, and valves
	Self-destruct systems
	Power for electric generators
	Power for gyroscopic guidance systems
	Power for control surfaces
	Separation of nose cones
	Inflation of flotation bags for recovery systems
	Detonators for warheads
Aircraft	
	Jettison of wing tanks, pods, and cargo
	Ejection of bombs, seats, rockets, and canopies
	Launching of aircraft, rockets and missiles
	Actuation of emergency hydraulic systems
	Starter units for jet engines
	Fuzes for bombs, rockets, and missiles
Shipboard	
	Primers for large guns
	Fuzes and charges for mines, depth charges, and torpedos

The adverse effects of RF excitation are not confined to accidental initiation. Heat generated by RF energy in the area of the bridge wire, even though it may be insufficient to ignite the primary explosive, can appreciably reduce its sensitivity. If continued over a period of time, this heat can render the primary mix so insensitive that the EED cannot be fired. This hazard, called "dudding," is as undesirable (from a reliability standpoint) as inadvertent initiation.

In pulsed RF environments, there occurs a phenomenon called "thermal stacking" which can increase the likelihood of inadvertent initiation or dudding. The heat generated by a single pulse of energy may be insufficient to initiate the EED; but if the time between pulses will not permit the bridge wire to cool, successive pulses can progressively elevate the bridge wire temperature until the initiation temperature is reached. Figure 5-10C, in which the heat increase is shown graphically, demonstrates that the temperature will rise from the ambient level until it reaches a final equilibrium point, after which no further increases will occur. This final temperature, which is a function of pulse amplitude, duration, repetition rate (duty cycle), and the thermal time constant, may be sufficiently high to cause dudding or even to initiate the EED. In considering the hazard in pulsed environments, the effects of thermal stacking must be considered.

There are two modes of RF excitation of an EED: the differential mode and the coaxial mode. In the differential mode, the two-wire line is balanced and the RF energy propagates to the EED between the two wires in the same manner as the normal DC firing current. This will cause joule (resistance) heating of the bridge wire. Figure 5-10B illustrates the differential mode of excitation. The coaxial mode of RF excitation is most obvious

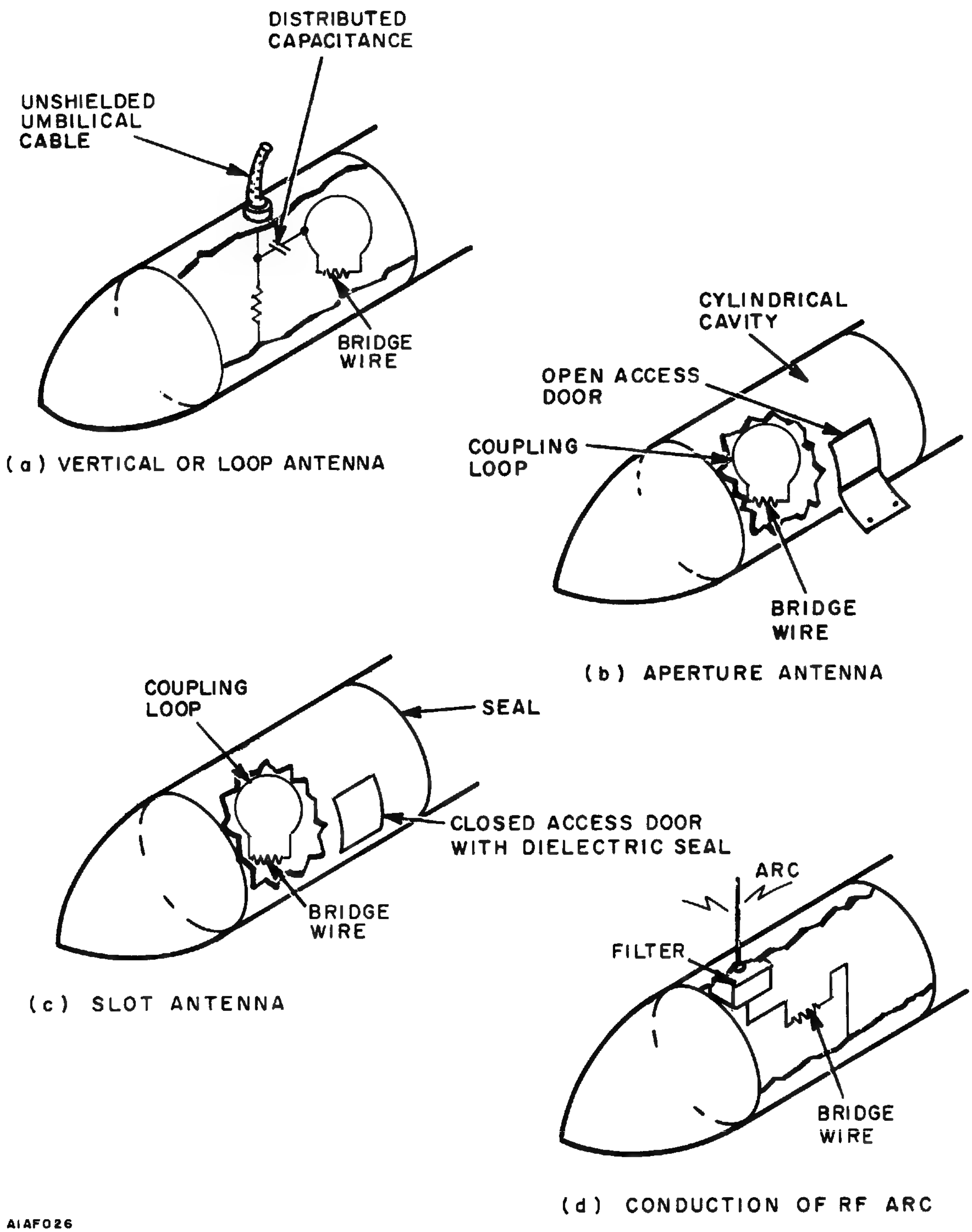


Figure 5-9. Methods of Coupling RF Energy into a Weapon

in coaxial type firing systems. Even though a two-pole balanced shielded system is used, however, a coaxial mode of excitation can be established from any break or high impedance connection in the shield continuity. Such a break is shown in figure 5-10D. The impedance (Z) is the return path through all preceding circuitry. The coaxial mode of excitation causes a high RF potential to be developed from the bridge wire through the explosive mix to the EED case.

In the differential mode of excitation, it might appear that if a large mismatch of impedance between the EED and the transmission line occurs, it would be difficult to effect a transfer of energy to the EED. It should be remembered, however, that although these impedance mismatches may exist, there is often sufficient energy available to induce hazardous amounts of current in the EED. In addition, the RF impedance of an EED differs considerably from its DC resistance, and it would be difficult to determine an EED's RF impedance under all conditions of application.

d. Information on hazards to electric blasting caps may be found in ANSI C-95.4, Safety Guide for the Prevention of Radio Frequency Radiation Hazards in the Use of Electric Blasting Caps.

5.2.5 RADHAZ to Equipment

a. General. Electromagnetic radiation of high-enough levels can cause physical, permanent damage to C-E equipments. The interaction of electromagnetic fields with dielectric materials is generally characterized by thermal heating, resulting in an increased "heat stress" of the material, while the interaction of X-radiation and materials is generally characterized by ionization of the atoms, resulting in possible changes in the molecular structure of the material. Since inadvertently emitted X-rays are usually confined to a small region surrounding the source, hazards to equipments from X-rays have a small probability of occurrence. Greatest emphasis, therefore, is placed upon the effects of electromagnetic energy upon equipment.

b. Electromagnetic Pulse. In recent years, work has been done on the effects of nuclear blast generated electromagnetic pulses (EMP). The electric and magnetic fields generated by a nuclear explosion can damage the sensitive equipment in use today. Basically, EMP has three transient effects: a pulse of ground current that flows radially from the point of explosion; a magnetic field pulse that propagates away from the point of explosion with the same vector components as from a vertical dipole; and a corresponding pulse of electric field. Each of these effects can cause damage to equipment, some examples of which follow.

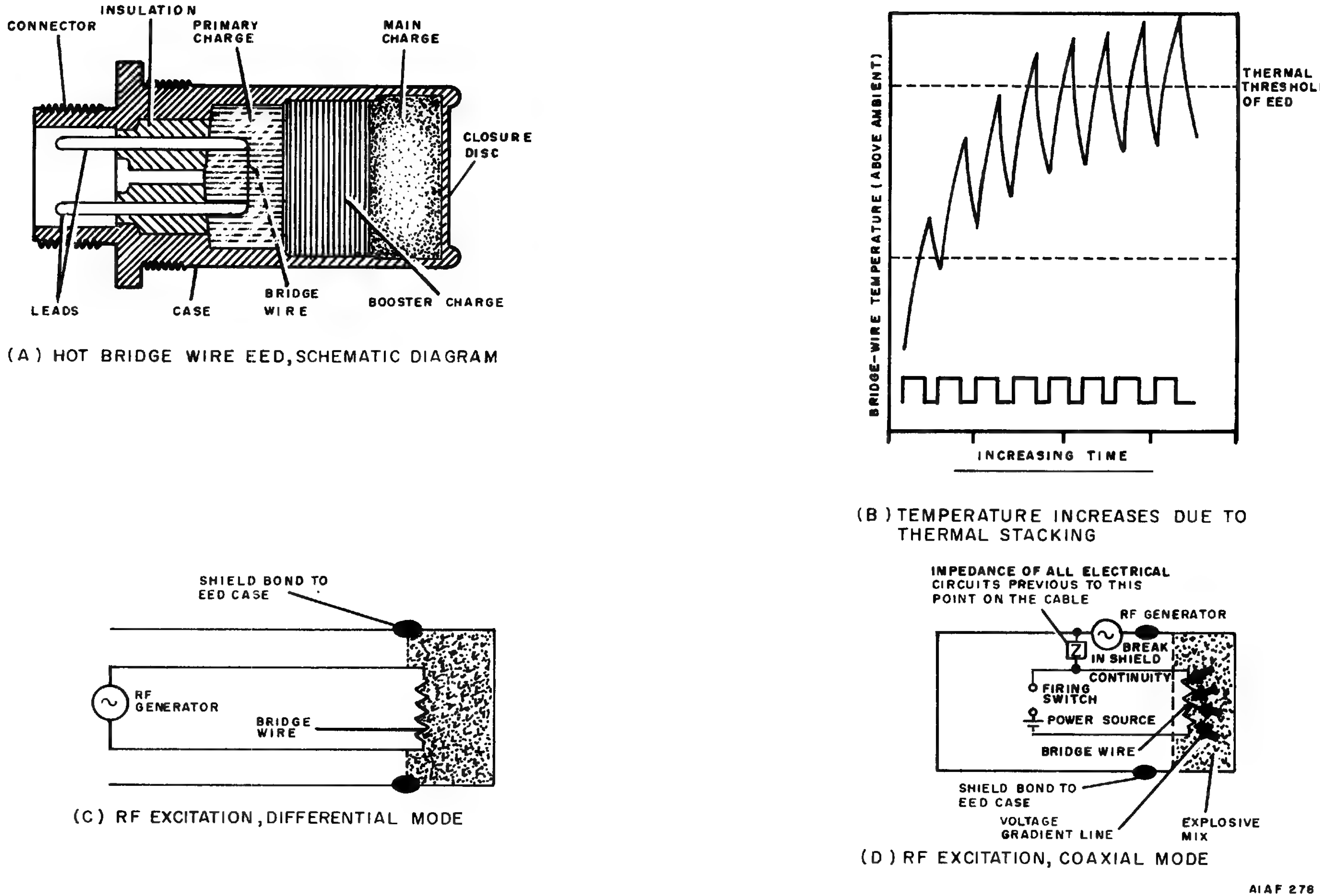
- Ground Current Damage. Buried communication or other cables may be damaged through rupture of insulation or crushed sheathing. An induced voltage pulse can travel down the cable conductors and damage associated equipment.

- Magnetic Field Damage. Peak flux and rate of change of flux may be of sufficient magnitude to destroy magnetic memories, induce high voltages in wiring with associated possible damage.

- Electric Field Damage. Induced voltage or current transients on high impedance, unshielded or unbalanced wiring may damage components of high susceptibility.

Detailed information on EMP effects and protective practices may be found in DASA Electromagnetic Pulse Handbook 2114, Office of Civil Defense document TR-GIA, and Oak Ridge National Labs document ORNL-TM-2830.

c. Solid State Damage. The mechanisms leading to damage to equipment from electromagnetic energy are complex. Damage commonly occurs at the circuit component level, i.e., transistor, diode, etc., and is a function of the type, level, and duration of exposure, the components or parts exposed, the nature of the electromagnetic field, and many other factors. Damage may occur from direct exposure to radiation via thermal heating or, more probably, from voltages or currents induced by electromagnetic fields at antenna terminals, circuit wiring, component terminals, power lines, etc.



(A) HOT BRIDGE WIRE EED, SCHEMATIC DIAGRAM

(B) TEMPERATURE INCREASES DUE TO THERMAL STACKING

(C) RF EXCITATION, DIFFERENTIAL MODE

(D) RF EXCITATION, COAXIAL MODE

Figure 5 - 10. Various Types of RF Excitation of an Electro-Explosive Device

Solid state circuitry is especially susceptible to peak levels and to rate of change of voltages and currents. Data on semiconductor burnout, for example, indicates that a range of 10^{-4} to 10^{-6} joules represents the threshold for semiconductor damage and possible subsequent equipment damage. Since burnout can occur in microseconds, even momentary exposure such as may occur from rotating or scanning antennas. represents a potential hazard.

In addition, arcing or corona caused by induced high voltages can damage relay terminals. antenna couplers and other components.

A knowledge of both the transient behavior and electromagnetic susceptibility characteristics of electronic parts is therefore necessary in order to select and apply optimum protective methods for C-E equipments.

Transistors and other semiconductors, including integrated circuits (microelectronics), are especially susceptible to damage from fast transients where peak-induced voltages exceed the maximum ratings of the device. The effects may be temperature sensitive, as in silicon devices where reverse breakdown voltage decreases with increasing temperatures. Since most transistors have an emitter-base reverse breakdown voltage of from 1 to 5 volts, it can be seen that they may be easily damaged. Voltage spikes can cause a build-up of impurities concentrated at a point in the collector and emitter junctions which can result in punch-through or internal shorting of the transistor at a later time. Both transistors and diodes operating in an electromagnetic field can absorb sufficient energy to cause the junction temperature to be exceeded, which may result in partial damage or total destruction. This is especially true if the device is operating at or near its rated junction temperature. Diodes are also subject to reverse breakdown by induced RF voltage in excess of the device rating. SCR's and other four-layer devices are sensitive to rate of change of forward voltages, as well as peak reverse voltages.

d. Medical Electronics Consideration. Recent investigations have shown that medical devices, such as cardiac pacemakers, hearing aids, and artificial limbs are susceptible to electromagnetic fields. For example, in the case of pacemakers, experiments with RF transmitters have demonstrated the possibility of inhibiting the production of pulses required for the pacing of the heart.

Damage to pacemakers, or even temporary inhibition of operation, can result in death. In the absence of definitive criteria as to hazardous levels and frequencies, it is best to prevent personnel using such medical devices from being exposed to RF radiation of any level.

5.2.6 Hazard Sources

Some of the major sources of electromagnetic hazards are; the intended fields emitted from radar and communications antennas, especially those types which concentrate electromagnetic energy into directed beams, extraneous radiations from cables and structures, and the unintended X-radiation from any device in which voltage levels exceed approximately 10kV, especially microwave and other electron tubes or devices using high plate voltages.

a. Antennas. Antennas may be grouped into two general classes: omnidirectional and directional. As their name implies, omnidirectional antennas radiate energy in all directions simultaneously. They are used chiefly in mobile communications, broadcasting sources, IFF (Identification, Friend or Foe), and similar equipment where broad area coverage is required. The omnidirectional antenna rarely presents a hazard problem (at least to personnel) for two reasons: its emitted energy is so spread out that power densities seldom reach hazardous proportion (a notable exception to this is the case of the region immediately surrounding a very high power broadcast antenna), and the operating frequencies used are not absorbed by the body. Directional antennas, on the other hand, radiate energy in relatively narrow lobes or beams that extend out from the antenna in one or, at most, a few directions. They are used for transmission between two fixed points, as in HF communications, microwave relays, etc., and for the many types of radar in use today. Because of their directional characteristics, i.e., the concentration of electromagnetic energy into narrow beams, and because of their use at extremely high powers, this category of antenna forms the major source of hazardous electromagnetic fields.

b. Electromagnetic Environment. For the purpose of describing the electromagnetic field or environment at a particular site, antennas may be grouped into classes according to the ratio of the antenna physical size to the wavelength of the radiated energy. Antennas are classed as large radiators when this ratio is much greater than unity, and as small radiators when of the order of, or less than, unity. Radar antennas are most frequently of the former class.

The field produced by an antenna may be partitioned into two distinct regions called the near field and the far field, as discussed in paragraph 5.1.2. For large radiators, that portion of the near field beginning one wavelength from the antenna (usually only a few centimeters for radar antennas) and extending to approximately $2D^2/\lambda$ where D equals the antenna diameter or maximum dimension, and λ equals the wavelength, is called the Fresnel region. The far field, or Fraunhofer region, begins at the approximate end of the Fresnel Zone, and extends to infinity. In actuality the ending of the Fresnel Zone and the beginning of the far field region is not a distinct line of demarcation, but rather a "cross-over" or transitional region exhibiting combined properties.

In the Fresnel region the radiated beam may be considered collimated, having a cross-section approximately equal to the projected area of the antenna aperture. The power along the axis of the beam is highly concentrated in this region because of the effects of the reflector. Since the beam is being formed in this region, the energy distribution across the beam is not uniform and both antenna gain and beamwidth vary with distance from the antenna. The above characteristics are also dependent upon the type of antenna illumination. This refers to the tapering of the energy distribution across the aperture, according to various mathematical relationships, in order to reduce the emitted sidelobes. A 10 dB taper from center to edge is usually employed, with maximum energy occurring at the center.

Beyond the Fresnel region, the radiated beam begins to spread out in a conical pattern until that region is reached in which the radiated energy may be considered to exist as uniform plane waves, and the power density along the axis decreases according to the inverse square law. This is the Fraunhofer or far field zone. Figure 5-11 depicts the various regions of a large aperture antenna.

(1) Power Densities In a Typical Radar System. Significantly different levels of electromagnetic energy exist in each radar system. In the typical radar system shown in figure 5-12, the highest power density exists within the waveguide which normally is closed and therefore not readily accessible. Power density, expressed in terms of average watts per square centimeter, is given approximately by the equation:

$$W \approx \frac{P}{A_t} \tag{5-2}$$

where:

W = power density, in average watts/cm^2

P = average power output of transmitter, in watts

A_t = cross-sectional area of transmission line, in cm^2

It should be noted that the power is not distributed uniformly over the entire area of the waveguide as implied by the equation 5-2 but the equation gives a close approximation.

The waveguide conveys the power to an antenna feed, which in turn feeds the energy on to the antenna. Before reaching the antenna, the energy from the feed is propagated through space which ordinarily is not enclosed, and is therefore more accessible to personnel than is the inside of the transmission line. The power density in the aperture of the feed is given, again approximately, by the equation in the preceding paragraph, except that the feed aperture A_f is now used instead of A_t. Since the feed aperture, A_f, is usually larger than the cross-sectional area of the waveguide A_t, the power density in the feed aperture is usually less than that in the line.

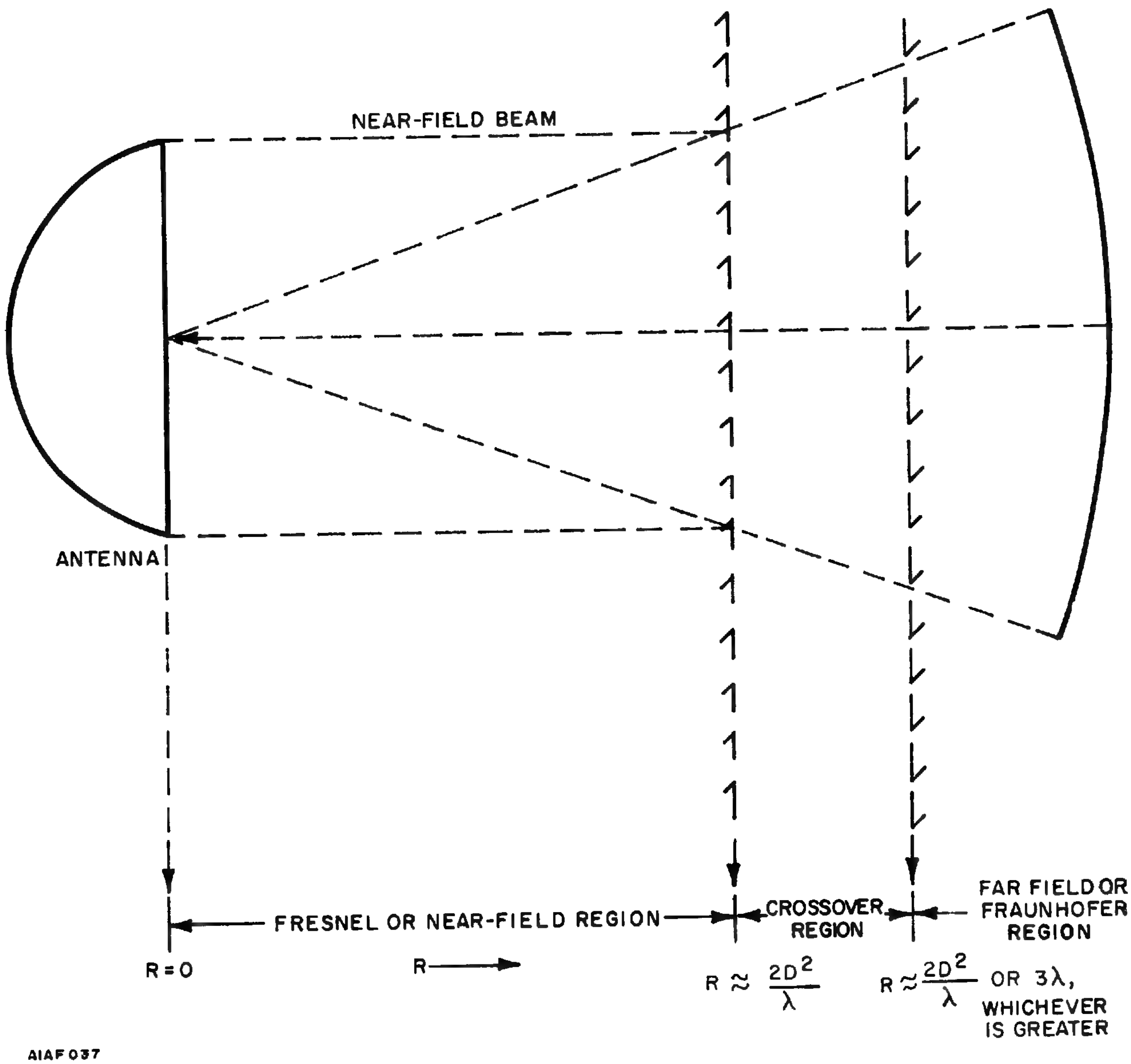


Figure 5 - 11. Antenna Radiation Region

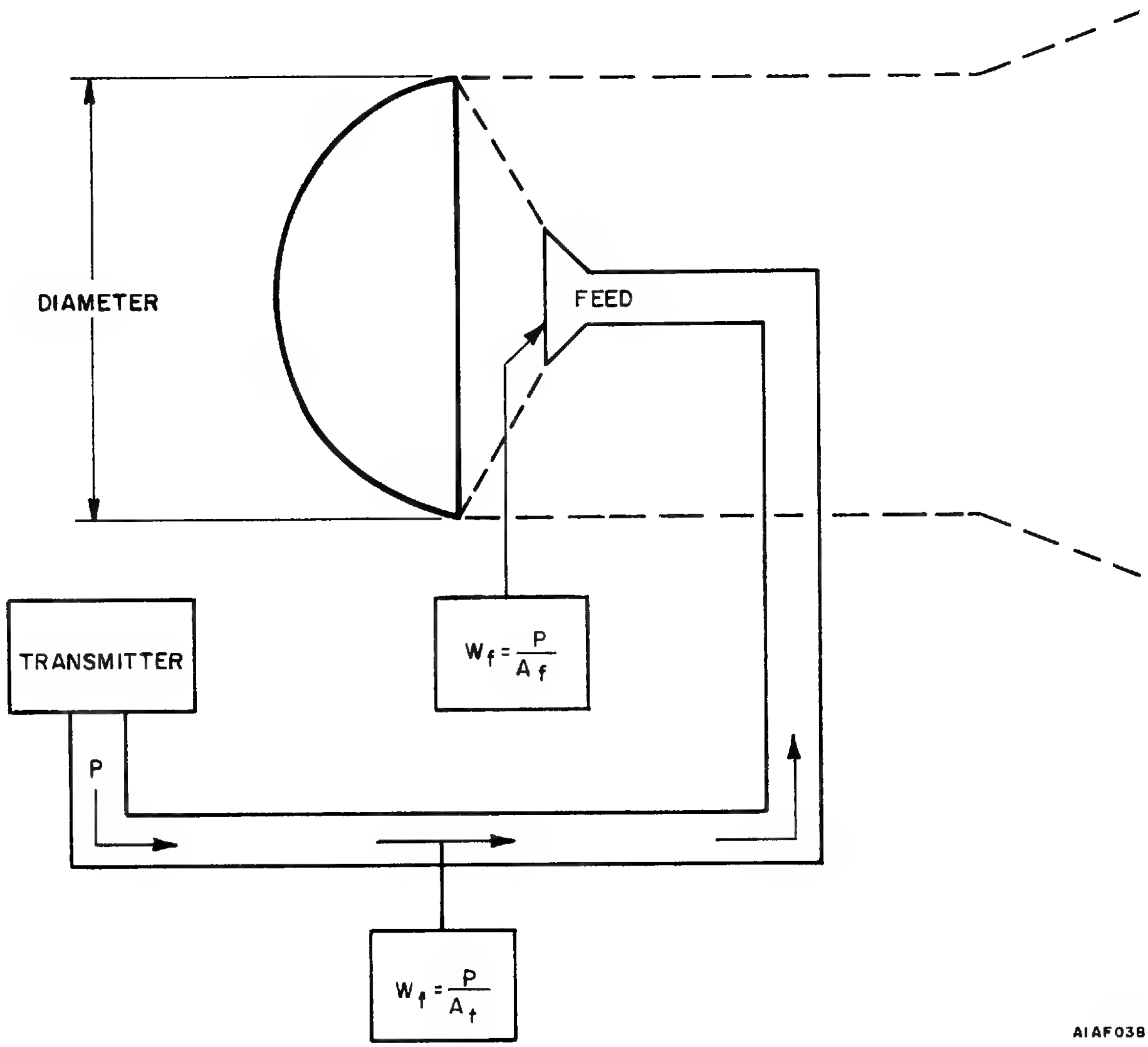


Figure 5 - 12. Typical Radar System Power Densities

From the antenna, the electromagnetic energy is radiated into free space. While the energy is travelling through space, it cannot be controlled. This fact constitutes one of the biggest problems in combatting possible hazards of this radiation.

The manner in which the radiated energy is emitted and interacts with the environment is complex and subject to many variations. Propagation of the emitted energy may be via ground waves, sky waves, or a combination of both, and is affected by the conductivity of the earth, ionospheric effects, absorption or reflection by obstacles and many other phenomena.

Ground and structural reflections, for example, may add to the main beam causing a value of power density which is four times the free-space value. Thus, fields at the threshold of hazardous levels in the absence of reflections can become hazardous at points where reflection occurs. The direction and type of polarization of the electric field vector also plays a role in determining the nature and extent of interaction between the field and personnel/materials. Analytical methods of determining power density levels of antenna fields are discussed in this handbook.

c. X-Radiation Sources. It is known that the high voltage tubes used in the generation, amplification and shaping processes associated with microwave and radar transmissions are inadvertent producers of X-radiation. Klystrons, magnetrons, travelling wave tubes, crossed-field amplifiers, thyratrons, high voltage rectifiers, CRO's and other tubes are thus sources of potentially hazardous X-rays. Generally, those tubes which operate at anode or accelerating voltages of less than about 15 kV, generate soft X-rays, i.e. low energy rays which usually do not penetrate the tube envelope. Higher voltage tubes, especially those operating under high intensity, low duty cycle pulse conditions, can produce hazardous radiation at distances of several feet from the tube. The energy of the emitted rays are a direct function of the square of the accelerating voltage, the average tube current and the target material atomic number. X-ray energy may increase as a tube ages, or if unstable operating conditions exist. Linear beam devices such as klystrons and travelling-wave tubes generally show greater X-radiation generation with the RF drive applied than with no RF drive. Emission from these devices generally occurs from the collector and electron gun ends, from cathode bushings and RF output windows, and, in the case of some high power devices, through the anode walls. Maximum intensity occurs at the collector assembly and output regions; with RF drive applied, the emission level can reach an average of 800 milliroentgens per hour, an extremely dangerous level.

5.3 HAZARD CRITERIA LEVELS

The presently accepted maximum exposure limits to EMR of various wavelengths for personnel, fuels and ordnance are discussed in the following paragraphs.

5.3.1 Personnel

a. EMR. The personnel limit of 10 mW/cm^2 for continuous exposure was adopted in 1957 by NAVMED. The intermittent exposure criteria of 300 mJ/cm^2 per 30 second exposure period was established for the case of exposure by rotating or scanning type antennas and is derived from the 10 mW/cm^2 figure. This permits higher levels of exposure for shorter periods of time (less than 30 seconds) up to a limit of 100 mW/cm^2 for one second in a 30 second period. Both of these figures are based on present knowledge, with consideration of the tolerable rise in tissue temperature.

b. X-Radiation. The limits given in table 5-6 for X-radiation were established by the Bureau of Medicine and Surgery. They are based on long experience with man working in a known radiation environment and reflect those dose levels which, in the light of present knowledge, will not cause appreciable injury to an average individual at any time during his normal life span. As additional knowledge is gained concerning the biological effects of X-Radiation, particularly for low-level exposures, the values listed are subject to revision.

c. Tables 5-7 and 5-8 present the maximum exposure limits established by NAVMED. Additional information may be found in NAVMED P-5055.

5.3.2 Fuels

The "safe" limit of exposure for fueling operations and fuel storage area is based on present "highly limited" knowledge of minimum voltage required for arcing and has not been generally accepted as the definitive criteria. The complete characterization of hazards to fuels probably requires that a complex, worst case, formula be developed which relates the parameters of fuel flammability limits, minimum gap spacing, and spark energy-time dependence. Due to the complexity of the variables that must be defined, development of this formula is prohibitive.

However, in assessing and reviewing the hazardous characteristics of fuels, the following information must be considered relative to energy and duration of arc, and gap distance.

o From actual measurements of voltages and currents on aircraft located on a carrier deck near an energized antenna, a volt-ampere product of fifty or more was required to ignite gasoline vapor in a test device. It should also be noted, however, that only 120 volts is necessary to draw an arc (that is, touch two electrodes and then separate) and that inductive surges energized by low voltage sources can yield sufficient voltage to produce sparks.

5.3.3 Ordnance

The levels for Ordnance are given in MIL-P-24014 as the environmental field levels to be used in the design of weapon systems to preclude spurious functioning or degradation of any EED. Figures 5-13 through 5-16 present currently accepted safe limits, as given in MIL-P-24014.* When evaluating hazardous situations relative to ordnance, to obtain details in the process refer to NAVMATINST 8020.1C, NAVELEXINST 5100.4, and NAVFAC 8020.2 and 8020.3 series regarding responsibilities.

Table 5-6. X-Radiation - Maximum Limits For Personnel

TYPE OF EXPOSURE	PERIOD OF EXPOSURE	DOSE IN REM WHICH SHOULD NOT BE EXCEEDED	NOTES
Whole body, head and trunk, active bloodforming organs, gonads or lens of the eye.	Calendar quarter	3	
	Permissible accumulated dose after 18th birthday.	5 (n-18) where n=age in years	Total life-time dose
Skin of whole body, or thyroid	Calendar quarter	10	
	Year	30	
Hands and forearms, or feet and ankles	Calendar quarter	25	
	Year	75	

* For current information, use latest issue of MIL-P-24014.

Table 5-7. Laser Radiation - Maximum Limits

CATEGORY	ABSOLUTE MAXIMUM LIMITS - 0.4 TO 1.4μ*			10.6μ CO_2
	Q-SWITCHED †	NON Q-SWITCHED	CONTINOUS	
Personnel Eye (Corneal Incidence)	5-50 ns Pulse width 10^{-7} J/cm^2	1.0 ms width 10^{-6} J/cm^2	10^{-6} W/cm^2	100 mW/cm^2
Skin	10^{-2} J/cm^2	10^{-1} J/cm^2	10^{-1} W/cm^2	100 mW/cm^2

*NOTE:

a) Safety factor of 2 recommended for field evaluation and training activities, excluding CO_2 laser.

b) Safety factor of 10 recommended for long term laboratory use, excluding CO_2 lasers.

† Q- Switching or Q- Spoiling refers to the operation of a laser in a pulsed mode to obtain high peak power of short duration.

Table 5-8. Laser Radiation- Maximum Allowable Limits

RADIANT INTENSITY FROM A DIFFUSE SURFACE REFLECTION AS MEASURED AT THE REFLECTING SURFACE		
Q-SWITCHED	NON Q-SWITCHED	CONTINUOUS
0.07 J/cm^2	0.9 J/cm^2	2.5 W/cm^2

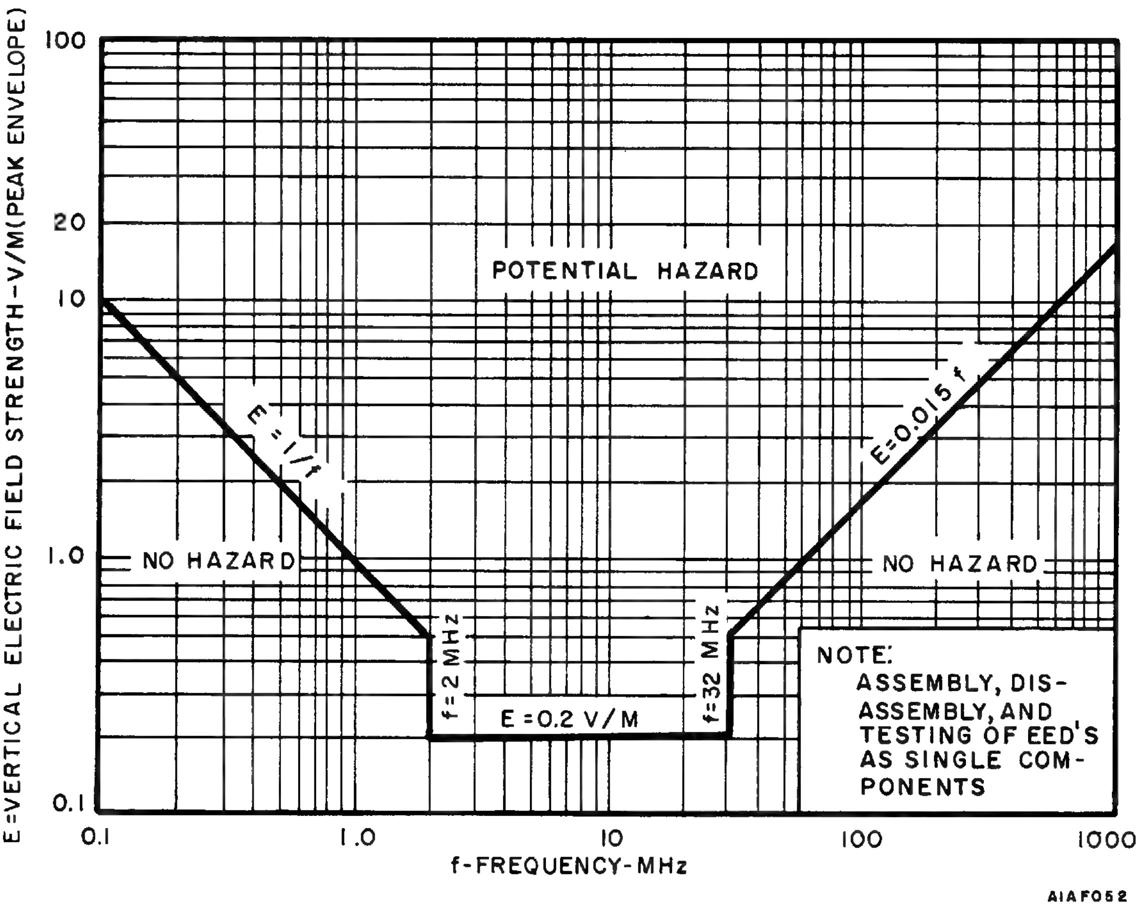


Figure 5 - 13. RF Field-Intensity Potentially Hazardous to Ordnance In Optimum Coupling Configurations-Radio Frequencies

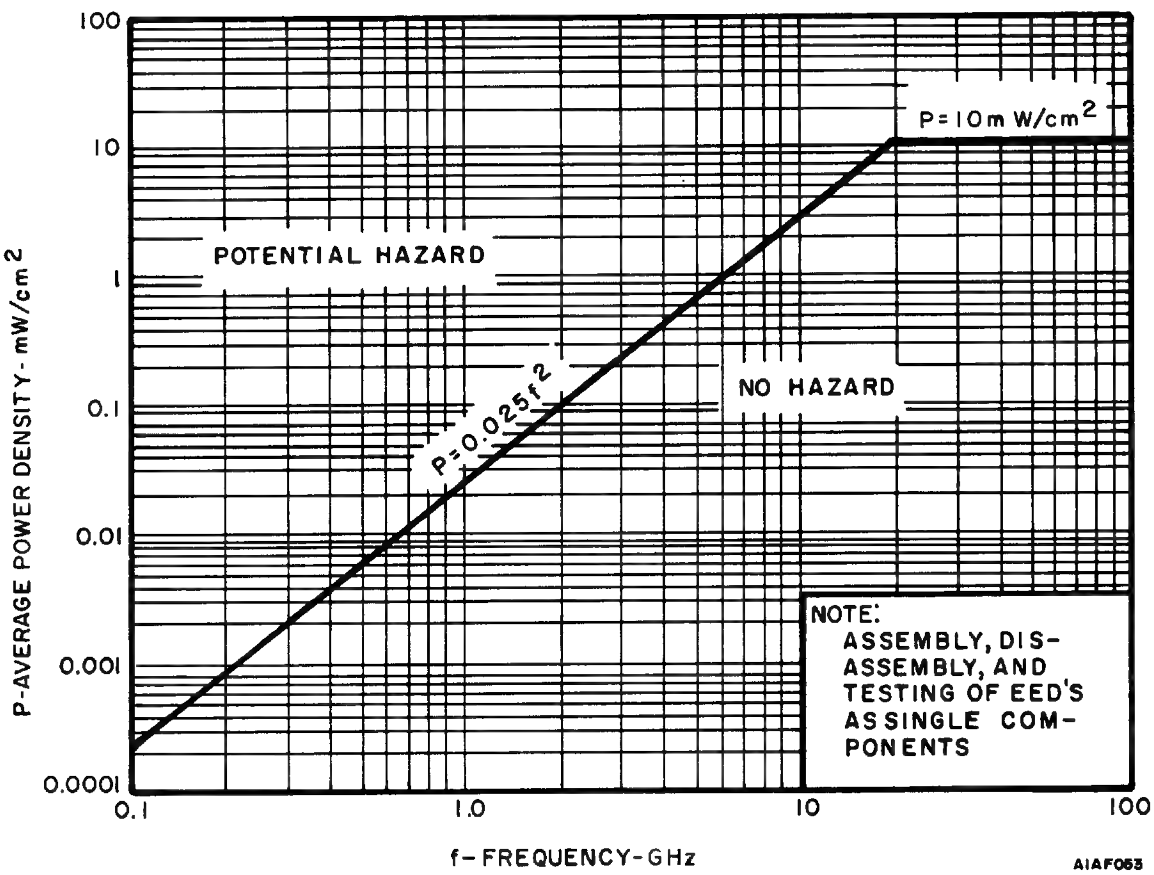


Figure 5 - 14. Radar-Frequency Field-Intensity Potentially Hazardous to Ordnance in Optimum Coupling Configurations

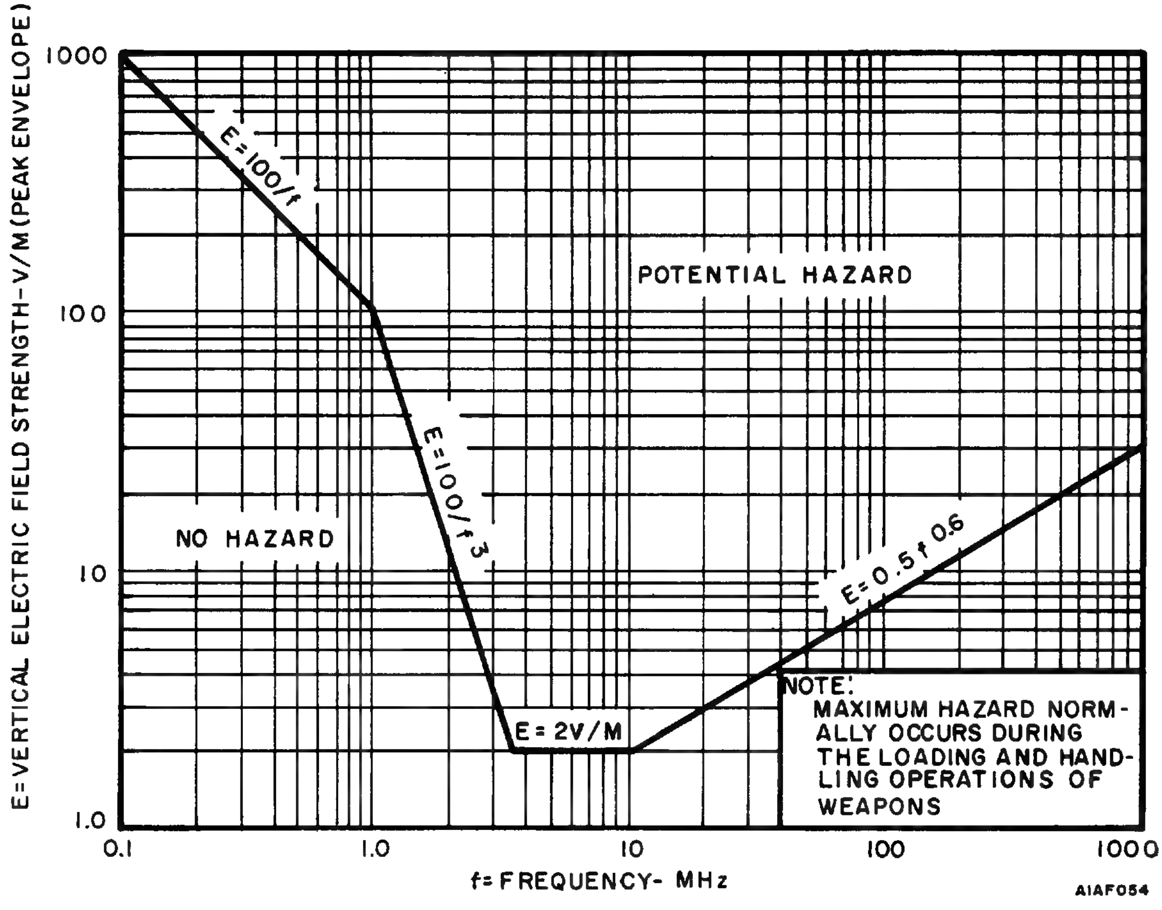


Figure 5 - 15. RF Field-Intensity Potentially Hazardous to Susceptible Weapons Which Require Special Restrictions

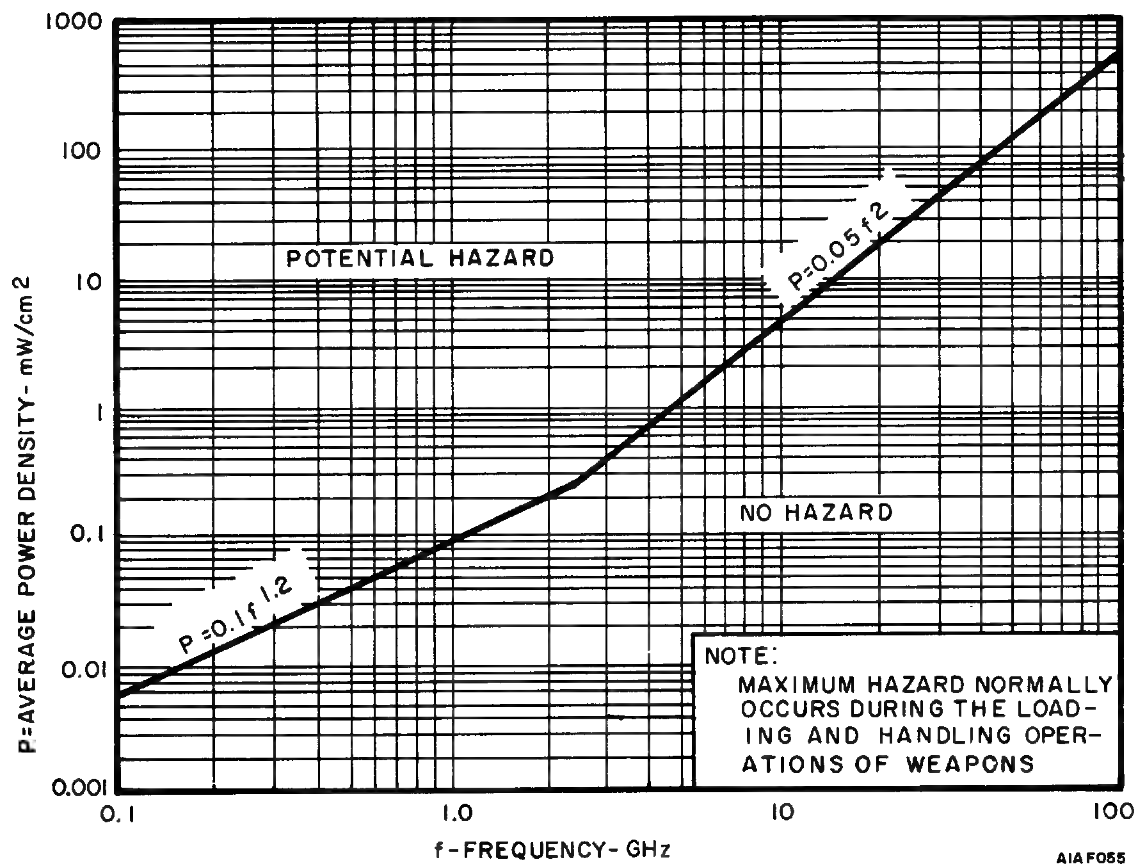


Figure 5 - 16. Radar-Frequency Power Density Potentially Hazardous to Susceptible Weapons Which Require Special Restrictions

CHAPTER 6

EVALUATION TECHNIQUES AND MEASUREMENTS

6.1 COMPATIBILITY EVALUATION TECHNIQUES

The Department of Defense, in its Directive 3222.3, has established a formal Electromagnetic Compatibility Program which includes the collection and establishment for a library of spectrum signatures among its provisions. A library of such spectrum signatures is maintained at the ECAC. OPNAVINST 2410.17 outlines naval responsibility for the collection and submission of spectrum signatures. MIL-STD-449 establishes the uniform measuring techniques to be used for such collections. Pertinent details regarding ECAC and the services provided are identified in paragraph 1.5.

6.1.1 General Considerations

In the planning and installation of C-E equipment at a new site, or in the addition of equipments to an existing site, the achievement of system compatibility is a required goal. The implementation of a formal EMC program to attain that goal will generally seek the answers to such questions as:

- o What are the effects of adding new sources of potential interference to an existing site?
- o What are the effects of changing operating schedules or operating frequencies of equipment within a site?
- o What are the potential interference problems within the site?
- o What are the causes of observed interference?
- o What solutions to interference problems are possible, and what is their effectiveness?

The answers to these and other related questions may be found through the establishment of an interference analysis or prediction process within the overall compatibility program.

The fundamental concept of the prediction process is to determine whether one or more sources within an electromagnetic environment generate emissions capable of producing interference at each susceptible equipment. To accomplish this, one must:

- o Identify the equipment and subsystem classes based on intended installation.
- o Identify ancillary or auxiliary equipment and subsystems which support and are used in the intended installation.
- o Identify ancillary or support equipment or subsystems which are not physically located in critical areas in the intended installation.
- o Identify equipment or subsystems used for general military needs which are not associated with a specific system.
- o Identify facilities equipment and subsystems installed in buildings or at sites.
- o Define or characterize the signals produced by the source(s).

o Determine the effects on the signals during transmission from the source to the susceptible or victim equipment.

o Define or characterize the susceptibility properties of the "victim" equipment.

o Determine whether the signals present at the susceptible equipment create interference.

o Request ECAC services in accordance with procedures stated in paragraph 1.5.

A prediction model is required to determine whether the signals present at the susceptible equipment create interference, i.e., a set of concepts, defined by mathematical formulas or procedures, by means of which the prediction is made. Many types of such interference prediction models may be found in the literature, each oriented toward different aspects of prediction, e.g., models for predicting antenna to antenna interference, cable coupling interference, case radiation interference, etc. Once the model has been selected, it may be implemented either by the use of manual calculations, charts, nomograms, etc., or by the use of computer techniques, depending on the nature and complexity of the model.

The characterizations of the source, transmission effects, and victim susceptibility must be determined. These characterizations serve as the input functions to the prediction model. In general, the characterization, or modeling, of these effects is a formidable task. The characteristics of transmitters, receivers and antennas, for example, must be modeled for a large number of equipments. Transmission effects must include the modeling of the many modes of radio propagation or other coupling phenomena, as applicable, and include such factors as site effects, obstructions, overhead powerlines, mobile equipment, etc. To confine the problem within reasonable bounds, certain simplifying assumptions are usually made during the equipment modeling process. These are outlined in following sections.

The basic input functions to the prediction process are generally represented by amplitude levels of either power, voltage or current as a function of time or frequency. In either representation, the input model must reflect the random nature of many of these functions with respect to such equipment parameters as equipment class or type number, tuned frequency, load impedances, etc. Thus, each of the input functions is obtained statistically through a combination of measurement and calculation, and is defined in terms of probability distributions which are either time independent or time dependent.

The indication of interference obtained by insertion of the input functions into the prediction model should be related to system or equipment performance requirements in order to achieve a more meaningful measure of compatibility. This requires the defining of objective degradation criteria.

A detailed model and prediction technique which demonstrates some of the concepts discussed above may be found in RADC-TR-66-1, Interference Notebook.

In those cases where the required statistical data is not available or cannot be adequately measured, an alternate prediction model is outlined in this chapter. The intent is to provide field engineering and installation personnel with a feasible and practical prediction model. Although the following is specifically detailed and outlined for EMI predictions, aspects of the techniques are applicable to RADHAZ predictions also.

6.2 BASIC PREDICTION TECHNIQUE

The basic prediction technique outlined herein makes use of the ON-AXIS, FREE SPACE, FAR FIELD transmission equation expanded to accommodate such additional factors as receiver noise level, losses due to obscured propagation, polarization misalignment, off-axis antenna orientation, interference level scoring criteria, and transmitter spurious modulation or sideband energy existing at frequencies lying in the passband of a receiver. An interference-to-noise ratio (I/N) is calculated, and then related to the operational receiver signal-to-noise ratio (S/N) to obtain a time-variant signal-to-interference ratio (S/I) at the receiver output. This S/I ratio is interpreted through the use of scoring tables which reflect the susceptibility of different types of reception to varying degrees of EMI.

The following one-way transmission equation applies for optimum conditions as stated.

$$P_D = \frac{P_t G_t}{4\pi R^2} \text{ watts/m}^2 \tag{6-1}$$

where:

P_D = power density (watts/m^2)

P_t = transmitted power (watts)

G_t = rated on-axis transmitter antenna gain

R = distance between transmitter and receiver (meters)

Since equation 6-1 represents power density and is based on optimum conditions only, some of the characteristics of the receiving equipment and other modifying factors are now introduced:

$$I/N = \frac{P_{tr} G_t A_r B_r}{4\pi R^2 L_p H L_t L_r N} \tag{6-2}$$

where:

I = the potential interfering power (in watts) existing at the receiver input terminals.

P_{tr} = transmitter output power existing within the 3dB bandwidth of the potentially interfered receiver (in watts/megahertz).

G_t = rated on-axis transmitter antenna gain (numeric).

A_r = effective aperture of the receiver antenna (in meters squared).

L_p = loss factor to account for possible polarization differences between the receiving antenna and the arriving wave (numeric).

H = propagation correction factor for other than free space or line-of-sight conditions (numeric).

L_t = transmitter antenna output transmission line loss (numeric).

L_r = receiver antenna input transmission line loss (numeric).

N = receiver internal noise power within its 3 dB bandwidth referred to the input terminals (in watts).

B_r = receiver bandwidth at 3 dB points (in megahertz).

Equation 6-2 provides the relationship of the transmitted interference power as referenced to the noise level of the receivers. The values computed using this equation are dimensionless. However, for ease of computation, it is desirable to have the values of each of the parameters in the right-hand side of the equation be in commonly used terms. For example, in normal practice the values of distance are usually given in statute miles, and the gain of the receiving antennas are generally given in terms of a ratio (dB above an isotropic radiator) rather than by

effective aperture. Therefore, equation 6-2 is further modified to permit the use of the more common values of the equation parameters. To do this, however, a constant of proportionality must be developed, so that the computed I/N values will remain a dimensionless ratio. Performing the indicated changes, therefore, equation 6-3 results:

$$I/N = \frac{KP_{tr}G_tG_rB_r}{RL_pHL_tL_rf_r^2N} \tag{6-3}$$

where:

P_{tr} is in watts/MHz
G_tG_r is antenna gain power ratios
B_r is in MHz
R is in statute miles
$L_pL_tL_r$ are power ratios
f_r is in MHz
N is in mW
K is a constant of proportionality

Since the signal-to-interference ratio (S/I) is a more direct measure of a given receiver-transmitter interference situation, it is generally used for predicting interference. To obtain the S/I for a given situation, the I/N ratio form Equation 6-3 is related to the receiver operational (not threshold) signal-to-noise ratio. This is done as follows:

$$(S/N)_{dB} - (IN)_{dB} = (S/I)_{dB} \tag{6-4}$$

Equations 6-3 and 6-4 represent the basic prediction technique which is portrayed on the EMI Prediction Calculation sheet (figure 6-1). Using these equations, a measure of potential interference between a given transmitter-receiver pair can be calculated. It is desirable to use measured data for each of the parameters in these equations which are represented on the EMI Prediction Calculation sheet. These measured data not only include the discrete equipment characteristics such as antenna gain, receiver sensitivity, etc., but also transmitter Effective Radiated Power (ERP) and power densities existing at a proposed or installed receiver location. To enable field personnel to efficiently use these measured data, Equation 6-3 is divided into the basic elements of an interference situation; transmitter, propagation, and receiver.

Once the basic EMI prediction and analysis tools are derived, it is necessary to define the overall prediction method in further detail. Thus, other supporting forms have been developed to document both the nominal and operational characteristics of the C-E equipments; document relative location plan and profile maps of the transmitter/receiver pairs; and record reasons for the elimination of certain transmitter/receiver pairs from a detailed EMI calculation.

6.3 C-E EQUIPMENT DATA DOCUMENTATION

The basic equipment data required to perform an interference analysis of a particular site complex include two basic types: (1) C-E equipment characteristics, and (2) environmental data. These classifications are presently used by the Department of Defense Compatibility Program. In the DOD Program, the C-E equipment characteristics have been termed spectrum signatures (MIL-STD-449).

1
2 TX ____________
3 RX ____________
4 CODE ____________
DATE OF FORM ____________

EMI PREDICTION CALCULATION

5 Transmitter (TX) ____________ Receiver (RX) ____________
6 TX Site ____________ RX Site ________ Separation ________ mi
7 TX Frequency (f_t) ____________ MHz RX Frequency (f_r) ____________ MHz
8 Frequency of Interference (f_i) ____________ MHz (f_i) is ____________ function of (f_t)
9 TX Antenna Polarization ____________ RX Antenna Polarization ____________

NO.	ENTRIES	COLUMN A +dB	B -dB	C +dB	D -dB
	1. TRANSMITTER				
	1.1 TX Power (Fill in radar TX or communications TX section)				
10	Radar TX — 1.1.1 Fundamental Cochannel Interference ($f_r = f_t$)				
	1.1.1.1 [10 log P_t] + 30				
11	1.1.2 Fundamental Adjacent-Channel Interference				
12	1.1.2.1 [10 log P_t] + 30				
	1.1.2.2 -40 log ($\pi\tau\Delta f_{MHz}$) see fig. 6-13				
13	1.1.2.3 - 20 log K				
14	1.1.3 Harmonic Cochannel Interference ($f_r = nf_t$)				
15	1.1.3.1 [10 log P_t] + 30				
	-dB down from f_o refer to table 6-5				
	1.1.4 Harmonic Adjacent-Channel Interference				
16	1.1.4.1 [10 log P_t] + 30				
17	1.1.4.2 -dB down from f_o				
18	1.1.4.3 -40 log($\pi\tau\Delta f_{MHz}$)				
19	1.1.4.4 -20 log K				
20	Comm TX — 1.1.5 Fundamental Cochannel Interference ($f_r = f_t$)				
	1.1.5.1 [10 log P_t] + 30				
21	1.1.6 Harmonic Cochannel Interference ($f_r = nf_t$)				
22	1.1.6.1 [10 log P_t] + 30				
	-dB down from f_o				
23	1.2 TX Transmission Line Loss: L_t(dB) see fig. 6-14, 6-15				
24	1.3 TX Antenna Gain: G_r (dB)				
25	1.3.1 Loss due to off axis pointing at RX				
26	1.3.2 Loss due to near field effect				
27	1.4 Subtotal Line 1.1.1 through Line 1.3.2 Column A				

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Figure 6-1. EMI Prediction Calculation Sheet (1 of 3)

Line	Item	A	B
28	1.5 Subtotal, Line 1.1.1 through Line 1.3.2, Column B		
29	1.6 Total [Line 1.4] - [Line 1.5] - Effective Radiated Power (dBm)		
	2. PROPAGATION		
	2.1 Constant		75.1
30	2.2 Wave Spreading, TX-RX Distance: -20 log R_{mi} (see fig 6-25)		
31	2.3 Reflection Field (see fig 6-26)		
32	2.4 Diffraction Field		
33	2.5 Scatter Field		
34	2.6 Subtotal: Line 2.1 through 2.5, Column A		
35	2.7 Subtotal: Line 2.1 through 2.5, Column B		
36	2.8 Total: [Line 2.6] - [Line 2.7]		
37	2.9 Power Density Existing at RX in $dBm/m^2/MHz$ Line 1.6 + 2.8		
	3. RECEIVER		
38	3.1 Loss due to Polarization Mismatch (Refer to table 6-9) Fill in 3.2 if known; if not, fill in 3.2.1 through 3.2.3.2		
39	3.2 RX Effective Area: 10 log A_r		
	3.2.1 Constant	38.6	
40	3.2.2 RX Frequency; -20 log f_{MHz} (see fig 6-34)		
41	3.2.3 RX Antenna Gain: G_r(dB)		
42	3.2.3.1 Loss due to off axis pointing at TX:		
43	3.2.3.2 Loss due to near field effect		
44	3.3 RX Transmission Line Loss: L_R(dB) (see figs. 6-14, 6-15)		
45	3.4 Subtotal: Line 3.1 through 3.3, column A		
46	3.5 Subtotal: Line 3.1 through 3.3, column B		
47	3.6 Total: [Line 3.4] - [Line 3.5]		
48	3.7 Received Interference Power: Line 2.9 + (Line 3.6) dBm		
	3.8 RX Bandwidth (BW) (Fill in only if one of the following situations exists)		
49	3.8.1 Fundamental Cochannel Interference Where $BW_{RX} < \frac{2}{\tau}$ 3.8.1.1 10 log $(0.5\tau BW_{RX})$ MHz		
50	3.8.2 Fundamental Adjacent Channel Interference 3.8.2.1 10 log (BW_{RX}) MHz		
51	3.8.3 Harmonic Cochannel Interference Where $BW_{RX} < \frac{2}{\tau}$ 3.8.3.1 10 log $(0.5\tau BW_{RX})$		
52	3.8.4 Harmonic Adjacent Channel Interference 3.8.4.1 10 log (BW_{RX}) MHz		
53	3.8.5 10 log (BW_{RX}) MHz		
54	3.8.6 -10 log (BW_{TX}) MHz		
55	3.9 RX Sensitivity in Units of -dBm: N dBm		
56	3.10 Subtotal: Lines 3.8 through 3.9, column A		

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Figure 6 - 1. EMI Prediction Calculation Sheet (2 of 3)

57	3.11 Subtotal: Lines 3.8 through 3.9, column B	
58	3.12 Total: [Line 3.10] - [Line 3.11] = Adjusted RX Threshold	
	4. PREDICTED INTERFERENCE LEVEL	
59	4.1 I/N Ratio, Total of Line 3.7 + Line 3.12	
60	4.2 Assumed or Known RX (S/N) dB Ratio	
	4.3 Predicted S/I Ratio	
61	4.3.1 For $I/N > 0$ dB; $(S/I)_{dB} = (S/N)_{dB} - (I/N)_{dB}$: Line 4.2 - Line 4.1	
	4.3.2 For $I/N \leq 0$ dB; $(S/I)_{dB} = (S/N)_{dB}$ No Interference Exists	

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Figure 6 - 1. EMI Prediction Calculaticn Sheet (3 of 3)

Environmental data also can be termed local operations characteristics. To differentiate between the concept of environmental data and spectrum signature, refer to figure 6-2. The environmental or local operations data refer to those characteristics, such as antenna height or orientation, which may be unique to a particular physical equipment site, but are not unique to a particular class or type of equipment which may operate in various site complexes. In addition to the basic equipment and environmental data, it is necessary to know the signal complex under study. A C-E equipment census is made which yields the total number and deployment of C-E equipments in the complex.

6.3.1 C-E Equipment Characteristics

The nominal equipment characteristics required for interference prediction have been formulated for radar and communications equipment. These characteristics are shown on separate data sheets for Radar (figure 6-3) and Communications Equipments (figures 6-4 to 6-6). Three separate forms are shown for the communications equipments since, often, different antenna systems are used. In the case of a system such as the AN/GRC-27 which includes transmitter, receiver and antennas, the forms can be combined.

The characteristics listed on the forms (figures 6-3, 6-4, 6-5, and 6-6) are all that are required to perform the manual prediction. However additional detailed characteristics may be used in performing a comprehensive interference prediction and analysis of a given situation. For example, in a first order prediction, carrier stability is not an important or necessary consideration. However, when considering the time variant or long term duration of an interference situation, this must be taken into consideration. A prediction may be made where the ultimate or final recommendation is to use frequency reassignment. In other words, operate transmitter "A" at 2700 MHz and operate receiver "B" at 2725 MHz. If transmitter "A" were the AN/FPS-6, this recommendation would soon be negated by the appearance of interference in a relatively short time. In this particular case, the AN/FPS-6 is known to drift considerably over specified periods of time.

Information to assist in completing the principal characteristics data sheets is provided in Table 6-1 for radar equipment and in Table 6-2 for communications equipments.

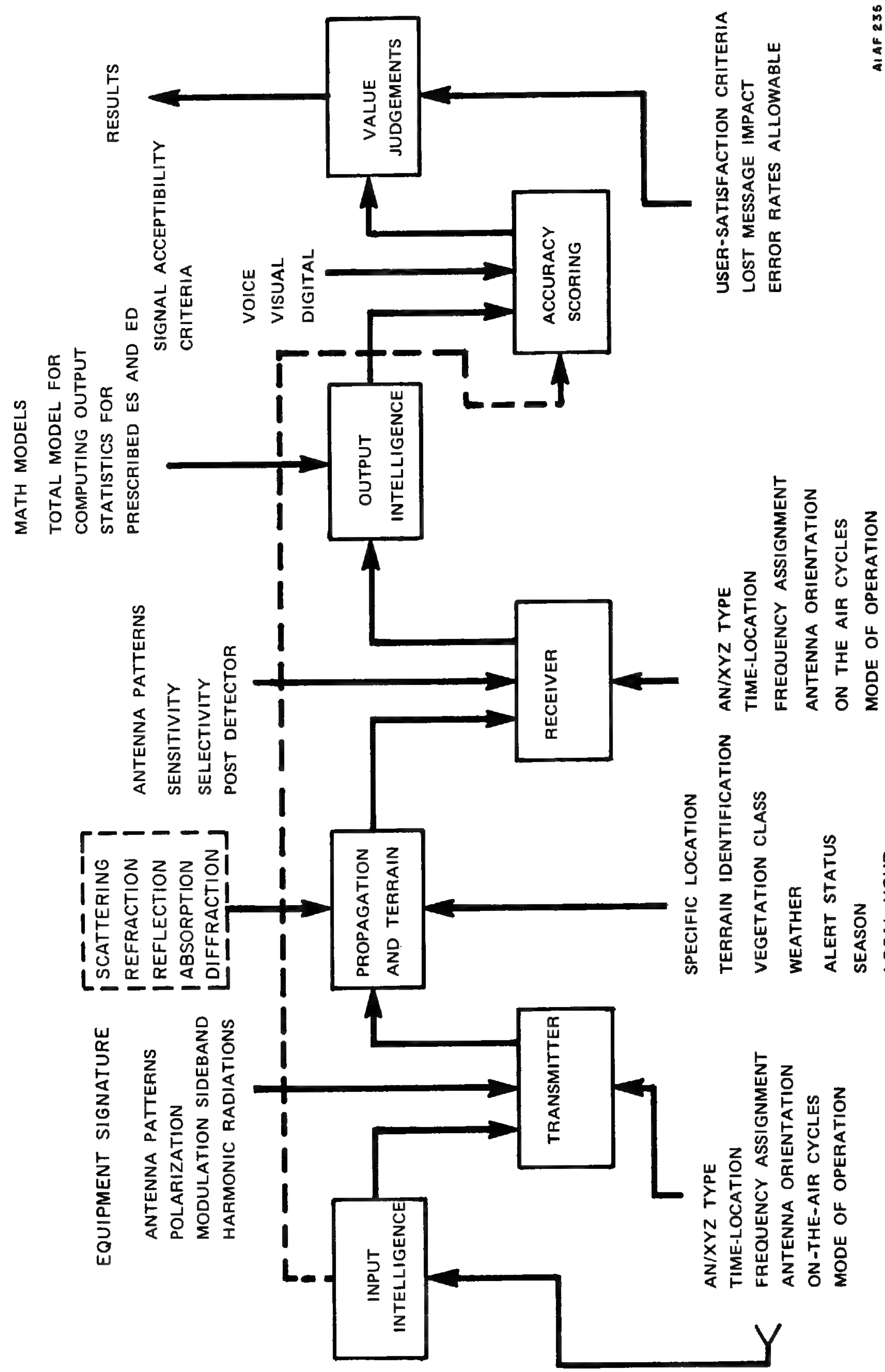

Figure 6-2. Factors Involved in a Single Transmitter/Receiver Interference Prediction

RADAR ____________________

Transmitter

Frequency Range ________ MHz to ________ MHz; Peak Power ________ kW

Pulse Width ________ μsec PRR ________ pps Pulse-shape factor ________

Receiver

Sensitivity ________ -dBm; Bandwidth (3dB) ________ MHz

Operational S/N ________ dB

Antenna ________ Type (describe) ________

Gain ________ dB Scan Rate ________ r/min

Polarization ________

Horizontal Beamwidth ________ Vertical Beamwidth ________

Remarks ____________________

AIAF 239

Figure 6 - 3. Radar Principal Equipment Characteristics Form

RECEIVERS

Receiver ____________________

Frequency Range ________ MHz to ________ MHz; Sensitivity ________ dBm

Bandwidth (3dB) ________ kHz; Operational (S/N) ________ dB

Type Emission Received ____________________

Remarks ____________________

____

AIAF238

Figure 6 - 4. Communications Principal Equipment Characteristics Form - Receivers

ANTENNAS

Antenna ____________________ Type(describe) ________________

Frequency Range __________ MHz to ________________ MHz; Gain _____________ dB

Polarization _________________________

Horizontal Pattern ______________ Vertical Pattern _____________

Remarks ____

____

AIAF 237

Figure 6 - 5. Communications Principal Equipment Characteristics Form - Antennas

TRANSMITTERS

Transmitter __________________________________

Frequency Range ___________ MHz to ________ MHz; Bandwidth ________________ kHz

Carrier Power, PEP _______________ kW;

Emission Type _______________

Remarks ____

____

AIAF 236

Figure 6 - 6. Communications Principal Equipment Characteristics Form - Transmitters

Table 6-1. Delineation of Radar Principal Characteristics Form

ENTRY	DESCRIPTOR	EXAMPLE
Principal Characteristics		
Transmitter		
Frequency range	Operating frequency range MHz	9000-10,000 MHz
Peak power	Peak power output in kW	10^4 kW
Pulse width	Duration of a single pulse	6 μsec
PRR	No. of times/second one pulse is repeated	300 pps
Pulse shape factor	Ratio of rise time + fall time to pulse width	0.10
Receiver		
Sensitivity	Threshold noise power level (FKTB) in dBm	-110 dBm
Bandwidth (3dB)	3 dB bandwidth	6 kHz
Operational S/N	RCVR S/N in dB (power)	10 dB
Antenna		
Gain	Power gain relative to isotropic antenna in dB	40 dB
Horizontal beamwidth	Horizontal 3 dB beamwidth in degrees	3°
Vertical beamwidth	Vertical 3 dB beamwidth in degrees	20°
Scan rate	Revolutions per minute	6 r/min
Polarization	Horizontal, vertical, circular	Circular

Table 6-2. Delineation of Communications Principal Equipment Characteristics Form

ENTRY	DESCRIPTOR	EXAMPLE
Principal Characteristics		
Receiver		
Frequency range	Operating frequency range in MHz	220 to 480 MHz
Sensitivity	Threshold noise power level (FKTB) in dBm	90dBm
Bandwidth	3dB bandwidth in kHz	5 kHz
(S/N) operational	RX output S/N in dB (power)	10dB
Type emission rec.	Standard emission symbols	A 3
Antenna		
Gain	Power gain relative to isotropic antenna in dB	6dB
Frequency range	Operating frequency range in MHz	220 to 480 MHz
Polarization	Horizontal, vertical, circular	Vertical
Horizontal beamwidth	Horizontal 3 dB beam width in degrees	3°
Vertical beamwidth	Vertical 3 dB beam width in degrees	20°
Transmitter		
Frequency range	Operating frequency range in MHz	220 to 480 MHz
Carrier power	Power in kW	0.1
Emission type	Standard emission symbols	A3
Bandwidth	Emission 3 dB bandwidth in kHz	6 kHz

6.3.2 C-E Equipment Local Operation (Environmental Data)

Environmental data consists of those characteristics which uniquely identify a transmitter or receiver in a complex such as an air station. These characteristics include location, terrain considerations, operational duty cycles, etc. The Environmental Characteristics Form is shown in figure 6-7. The upper right hand corner of the form includes information to enable quick storage and retrieval of the particular completed environmental form. Refer to Table 6-3 for details relative to the entries on the form.

The layout of a Naval Shore Station is such that there are several equipments of the same type at a site. For example, at a VHF/UHF transmitter site, there might be six AN/URT-7 transmitters and five TV-6 transmitters. One copy of the form is required for the AN/URT-7 at the site and one copy for the TV-6 at the site. If an AN/URT-7 is also installed at another site, such as in the control tower, a second copy of the form should be completed to provide the environmental characteristics of the equipment at that site.

6.3.3 C-E Equipment Census

The simplest method for preparing a complete presentation of the environment or census is to complete the C-E Equipment Data Sheets, the Environmental Data Sheets, and then plot the location of each equipment on a contour map of the area. A contour map (contour intervals of 25 to 100 feet) is recommended because of the effects of terrain on the propagation of electromagnetic radiated signals. However, if the terrain is relatively smooth, as is the case with most stations, this type map is not necessary, however it is important that the relative location of the equipments be plotted. At most Naval Shore Stations, frequencies are assigned to functions, therefore, it is also desirable to have a list of the frequencies assigned to the station and their use.

6.4 PRELIMINARY SORTING

Analysis of a complex for EMI consists in viewing each receiver in turn to determine to what extent its optimum performance will be reduced by the environment. In those cases where the performance is reduced, it is necessary to identify the transmitters causing the degradation.

In a complex such as a shore station the large number of receivers requires that some sequence of examination of possible interference be developed. This order may be based on the priority of the circuit involved or on the basis of circuits which presently experience interference that should be reduced or eliminated.

Once this sequence has been established, the next step is to readily identify those transmitters on the station which will not interfere with the receiver under consideration, so that they may be eliminated from the detailed analysis.

This rapid identification or rapid culling of non-interfering transmitters is actually a very coarse form of the basic prediction technique incorporating transmitter-receiver frequency separation, effective radiated power, and the effects of terrain masking.

The rapid cull technique presented in the following paragraphs is a go/no-go method based, for the most part, on extremely pessimistic (i.e., interference prone) conditions. A basic form which can be used for recording the C-E equipment information with regard to each receiver is shown in figure 6-8.

6.4.1 Frequency Sorting

The simplest method for quickly eliminating transmitters which will not interfere with the receiver under study is to compare the receiver frequency with the frequencies being radiated by each transmitter within the complex. When certain relationships exist between the receiver frequency and the frequencies of a transmitter, the latter can be eliminated as a possible source of interference to the receiver. It is possible that signals in combination with other signals may cause interference but this type of interference (e.g., intermodulation) is beyond the scope of this manual technique.

Site ______
Equipment Nomen: ______
Code ______ Revision ______
Date of Form ______

ENVIRONMENTAL CHARACTERISTICS

1. Equipment Operated By:
☐ Army ☐ Air Force ☐ Other ______
☐ Navy ☐ Marine Corps

2. Organizational Unit Designation

EQUIPMENT LOCATION

3. City/Base

4. State

5. Equipment Mobility
(Mark One) ☐ Fixed (Fill Item 7)
☐ Mobile (Fill Item 6) (Frequency Moved)

6. For Frequency Moved Equipment Only
☐ Shipborne (Indicate hull number)
☐ Airborne (Indicate aircraft type)
☐ Ground Based (Indicate unit)
☐ Other (Indicate what) ______

7. Site Information (For fixed equipment only)
A. Elevation (In feet above mean sea level) ______ feet
B. Latitude Degrees Min Sec
☐ North ___ ___ ___
☐ South
C. Longitude
☐ East ___ ___ ___
☐ West

D. Terrain (Mark applicable items)
☐ Dry Sand & Rock ☐ Streets & Bldgs.
☐ Grass and/or Farmland ☐ Swampland
☐ Wooded ☐ Water
☐ Other ______
E. Source of Data
☐ Map ☐ Survey
☐ Other ______

F. Screening Angle (For fixed equipment only)
(Mark one for each elevation)

Clear	Elevation Angle	Screened or Blanked	Degrees (Reference true north) 0 30 60 90 120 150 180 210 240 270 300 330 360
☐	30°	☐	
☐	20°	☐	
☐	10°	☐	
☐	5°	☐	
☐	0°	☐	
☐	−2°	☐	
☐	Other	☐	

8. Equipment Data
A. Nomenclature ______ B. Serial Number ______
C. Other Identifying Information ______
☐ Transmitter ☐ Transmitter-receiver combination (e.g.) radar, beacon, transceiver, etc.
☐ Receiver
D. List call sign, site number or station code if applicable ______

9. Antenna Nomenclature or Type ______

10. Antenna Height, Geometric center of antenna above site elevation ______ feet

11. Antenna Horizontal Motion Rate, For scanning specify RPM and percent of time used)
Scanning Rate ______ ______
Percent of Time ______ ______

12. Antenna Orientation
A. Elevation (Indicate angle of electrical axis of lowest beam, if fixed) ☐ Plus ☐ Minus ______ degrees
B. (Mark either "Fixed" or "Scanning" and complete appropriate block)
☐ Fixed — Azimuth Degrees (Reference true north)
☐ Omnidirectional ______
☐ Other (Specify Orientation) ______
☐ Scanning From: ______ degrees To: ______ degrees
☐ Height Finder ☐ Rotating (360°)
☐ Tracking ☐ Horizontal Sector Scanning

13. Antenna Polarization ☐ Horizontal ☐ Vertical

AI AF 241

Figure 6-7. Environmental Characteristics Form (1 of 2)

EQUIPMENT OPERATION

14. EQUIPMENT OPERATIONAL DUTY CYCLE (Mark One)

☐ Equipment ON THE AIR 24 hours a day, 7 days a week. (Skip to Item 15)

☐ Equipment off at all non-designated times. Fill in (a) through (d) below

(a) Normal Operations

	Daylight clear	Daylight low visibility	Night	Other
the air	☐	☐	☐	______

(b) Operations during alert conditions

☐ Yes, percent of time per week on ______ %

(c) ☐ Mark here if this equipment is used primarily as a spare or back up

(d) Indicate any weekly, monthly or seasonal changes. Also, any long term scheduling ______________

15. POWER (Transmitters only)

Indicate power normally transmitted. Also indicate whether peak, average, carrier or peak envelope power is recorded below

Power (kW) Percent of time used (Mark One)

Power (kW)	0–5	6–50	51–95	96–100
______	☐	☐	☐	☐
______	☐	☐	☐	☐
______	☐	☐	☐	☐

16. WHERE EXACT FREQUENCIES are assigned or used, indicate those frequencies. In other cases, estimate normal (operating frequency or frequencies. If more than one frequency is used, indicate approximate percentage of total operating time each frequency or frequeny band is used. (Describe any schedules not covered below in Item 20)

Frequency (Megahertz) Percent of time used (Mark One)

Frequency (Megahertz)	0–5	6–50	51–95	96–100
______	☐	☐	☐	☐
______	☐	☐	☐	☐

17. PRIMARY EQUIPMENT USAGE

(Mark One)

☐ Military Operations and Training

☐ Training Only

☐ Research and Development

☐ FAA

☐ Operation is necessary for air traffic control in high density air traffic regions

☐ Equipment operation is on a non-interference basis only

18. FOR PULSE EQUIPMENT ONLY

Pulse Width (microsec.)	PRR (pulse per sec.)	Percent of time used (Mark one for each Pulse Width or PRR combination) 0-5	6-50	51-95	96-100
______	______	☐	☐	☐	☐
______	______	☐	☐	☐	☐

19. MODULATION TYPES (Percentage of total operating time per Modulation Type that this equipment uses)

Modulation Type	Percent of time used (mark one) 0-5	6-50	51-95	96-100
______	☐	☐	☐	☐
______	☐	☐	☐	☐

20. PROVIDE ANY ADDITIONAL INFORMATION, OR REMARKS, THAT SHOULD BE CONSIDERED (Use separate sheet if necessary)

NAME, GRADE OR RANK, TITLE AND ORGANIZATION OF PERSON COMPLETING THIS FORM.

(NAME) ______________ Grade or Rank ______

(TITLE) ______________

(ORGANIZATION) ______________

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Figure 6 - 7. Environmental Characteristics Form (2 of 2)

Table 6-3. Delineation of Environmental Characteristics Form

ENTRY	DESCRIPTOR	EXAMPLE
1. Equipment operated by	Cognizant operating service	USN
2. Organizational unit designation	Specific operating group	387th Recon. Sqdn
3. City/base	Name of nearest base and/or city	Cherry Point, NAS,
4. State		North Carolina
5. Equipment mobility	Check one	Fixed
6. For frequently moved equipment only	Check one	Land based
7. Site information		
a. Elevation	Feet above mean sea level	400 ft
b. Latitude	Degrees, minutes, seconds	40°30′22″N.
c. Longtitude	Degrees, minutes, seconds	22°15′0.8″ W.
d. Terrain	Type of terrain	Water; rocks
e. Data source	Check one	Map
f. Screening angle	Mark sector for each elevation	
8. Equipment data		
a. Nomenclature	AN or commercial designation	AN/FPS-3
b. Serial number	Equipment serial number	
c. Other identifying information	Check one	
d. List all sign, site no., station code, if applies		Site no. 93
9. Antenna nomenclature or type	Specify military or commercial designation	
10. Antenna height	Geometric center of antenna above local terrain to nearest foot	35 feet, 25 feet

Table 6-3. Delineation of Environmental Characteristics Form (Continued)

ENTRY	DESCRIPTOR	EXAMPLE
11. Antenna horizontal motion rate	For scanning specify RPM and percent of time used	S R. =6 r/min % of time used = 22%
12. Antenna orientation		
a. Elevation	Indicate angle of electrical axis of lowest beam if fixed	
b. Azimuth	Mark either "fixed" or "scanning" & complete appropriate block	
13. Antenna polarization	Specify nominal polarization and alternate when applicable	
14. Equipment operation duty cycle	Mark one, and fill in (a) through (d) as appropriate	
15. Power (XMTR only)	Indicate power normally used and whether it is average, carrier or peak envelope power	5kW, 51-95% 20kW, 6-50%
16. Frequencies	Give exact frequency where assigned and used; otherwise, normal operating frequency, + % of time	30 MHz, 96-100%
17. Preliminary equip. usage	Description of equipment use	
18. Pulse equipment	Pulse characteristics and percentage of use for each set of characteristics	24 μ sec; 1000 pps; 96-100% 22 μ sec; 224 pps; 0-6%
19. Modulation types	Type of modulation and percentage of use	FM; 51-95%
20. Remarks	Provide any additional pertinent information or remarks (Name, grade, or rank, title and organization of person completing form)	Joe Smith, Ensign, USN Com. Engineers,

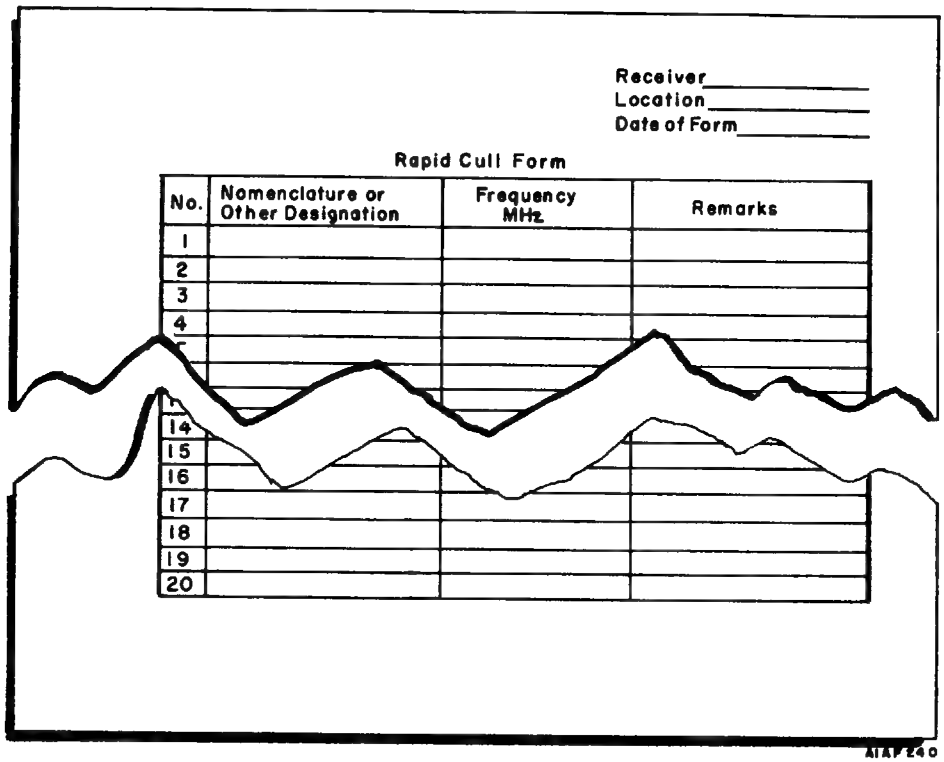

Figure 6 - 8. Rapid Cull Form

The flow diagram shown in figure 6-9 can be used to quickly examine the frequency relationships and determine the transmitters that can be eliminated as potential sources of interference and those that should be retained for further analysis.

The procedure has been designed so that the calculations required for each step need only be made once for each receiver. These values can then be compared rapidly with the fundamental frequency of any number of transmitters without further calculations. The harmonics of each transmitter are taken into account in the receiver calculations.

In cases where a large number of equipments exist or time is at a premium, a very rapid first sorting may be desired. For this situation, the portion of the diagram contained in the dashed section should be eliminated. While the existence of certain frequency relationships within this portion may cause interference, the probability is much lower that interference will exist for these relationships than those in the remaining portion of the diagram. In performing this very rapid sorting operation, any transmitter for which the process leads into the dashed area may be eliminated as a possible source of interference.

In a complex such as a Naval Shore Station, transmitters are often operated on various frequencies depending on the particular requirement. For example, a certain transmitter may be used one day on a tactical frequency and the next day on a point-to-point frequency. Therefore, when examining possible sources of interference to a receiver, it is almost impossible to specify the operating frequency for each transmitter.

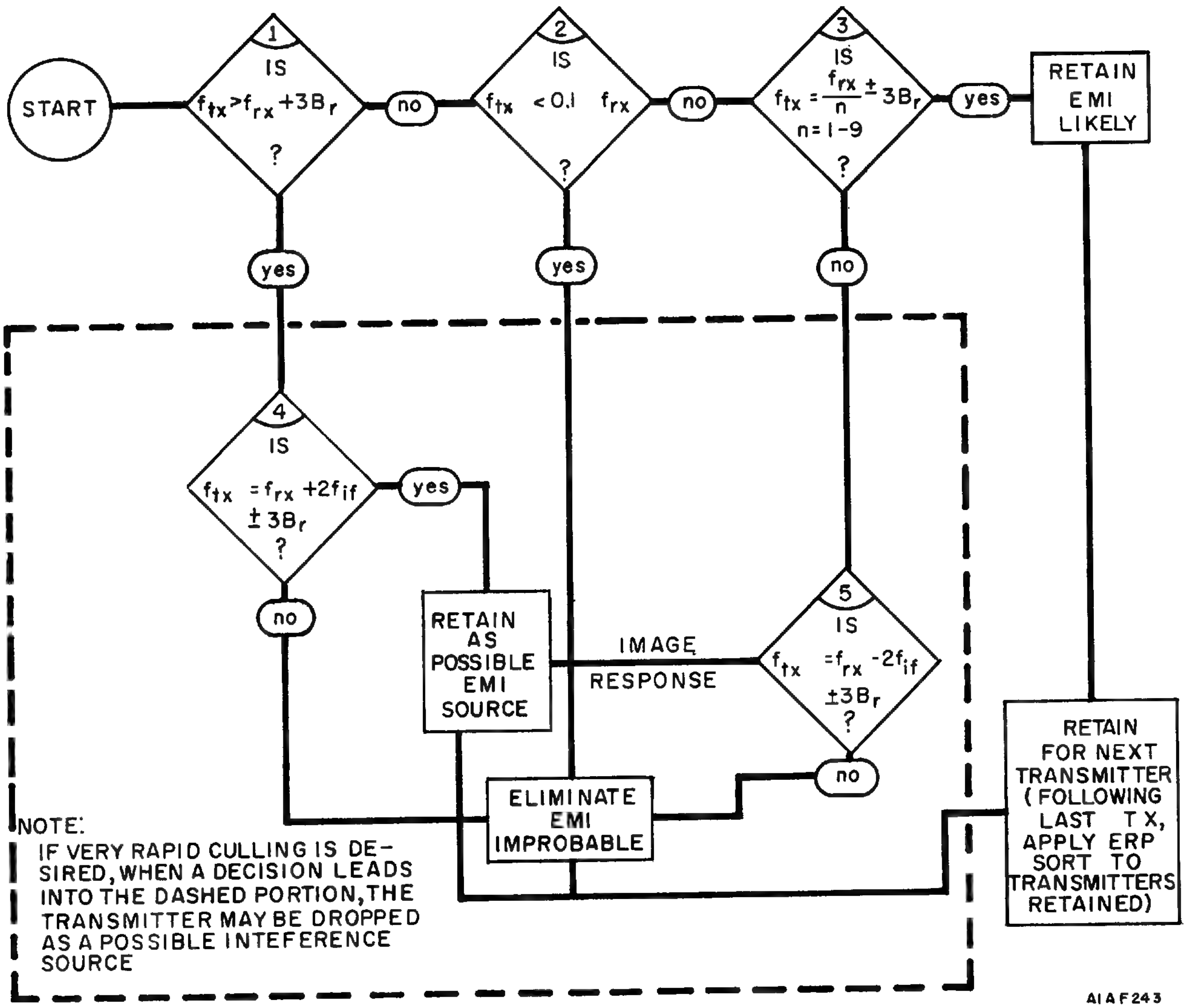

Figure 6-9. Flow Diagram for Rapid Frequency Sorting

The rapid frequency sort, with minor modifications, can be used to eliminate from further consideration transmitters that will not cause interference, no matter where within their frequency range they are operating.

The modifications are (refer to figure 6-9):

(1) Substitute the lowest operating frequency of the transmitter f_{tx} in diamond (1)

(2) Substitute the highest operating frequency for f_{tx} in diamond (2)

(3) If any of the receiver frequency bands determined in diamond (3) fall within the transmitter frequency band, operation of the transmitter on these frequencies may cause interference.

(4) For the more detailed frequency sort, it should be determined if any of the transmitter frequencies equal the f_{tx} values in diamonds (4) and (5), if so, operation on these frequencies may cause interference.

In addition to its use for eliminating transmitters from further analysis as interference sources, this flow diagram can be used to select frequency bands for a transmitter that will not interfere with any of the subject receivers. If sufficient frequency channels are available, this process will facilitate frequency assignments, such that the possibility of interference will be very small.

6.4.2 Effective Radiated Power and Propagation Loss Sorting

In addition to the frequency sorting just discussed, additional surviving transmitters can be eliminated as potential sources of interference by considering the Effective Radiated Power (ERP) of the transmitter.

In order for a transmitter to interfere with the operation of a receiver, it must radiate a signal that will exceed a certain level at the receiver terminals. This level is determined by the strength of the desired signal, frequency of the signal, sensitivity of receiver, and many other considerations.

However, by calculating the transmitter signal strength at the receiver and assuming the receiver to be very sensitive, it is possible to eliminate transmitters because their radiated power is inadequate to cause interference to the receiver under study.

A nomogram (figure 6-10) has been prepared which can be used to rapidly eliminate those transmitters which will not cause interference. In order to use the nomogram, the required variables are:

a. Transmitter power in dBm

b. Sum of antenna gains for transmitter and receiver

c. Path loss is a function of frequency and distance between transmitter and receiver. It can be obtained from figure 6-11.

To use the nomogram: (1) draw a line from the transmitter power on Line 1, through the gain value on Line 2 to Line 3; (2) draw a line from the intersection on Line 3 through the path loss value on Line 4 to Line 5; (3) if the final point lies below the criteria for the type receiver being considered it may be rejected as a possible source of interference.

The criteria has been set so that no transmitters which interfere with the receiver will be rejected.

6.4.3 Geographic Sorting

Another method of eliminating probable non-interfering transmitters is based on an analysis of the terrain between the transmitters and the receiver under consideration. When it can be determined that the receiver is beyond the Radio-Line-Of-Site (RLOS) of a transmitter, the transmitter can be eliminated as a possible source of interference. The term Radio-Line-Of-Site (RLOS) refers to the unobstructed propagation path of electromagnetic

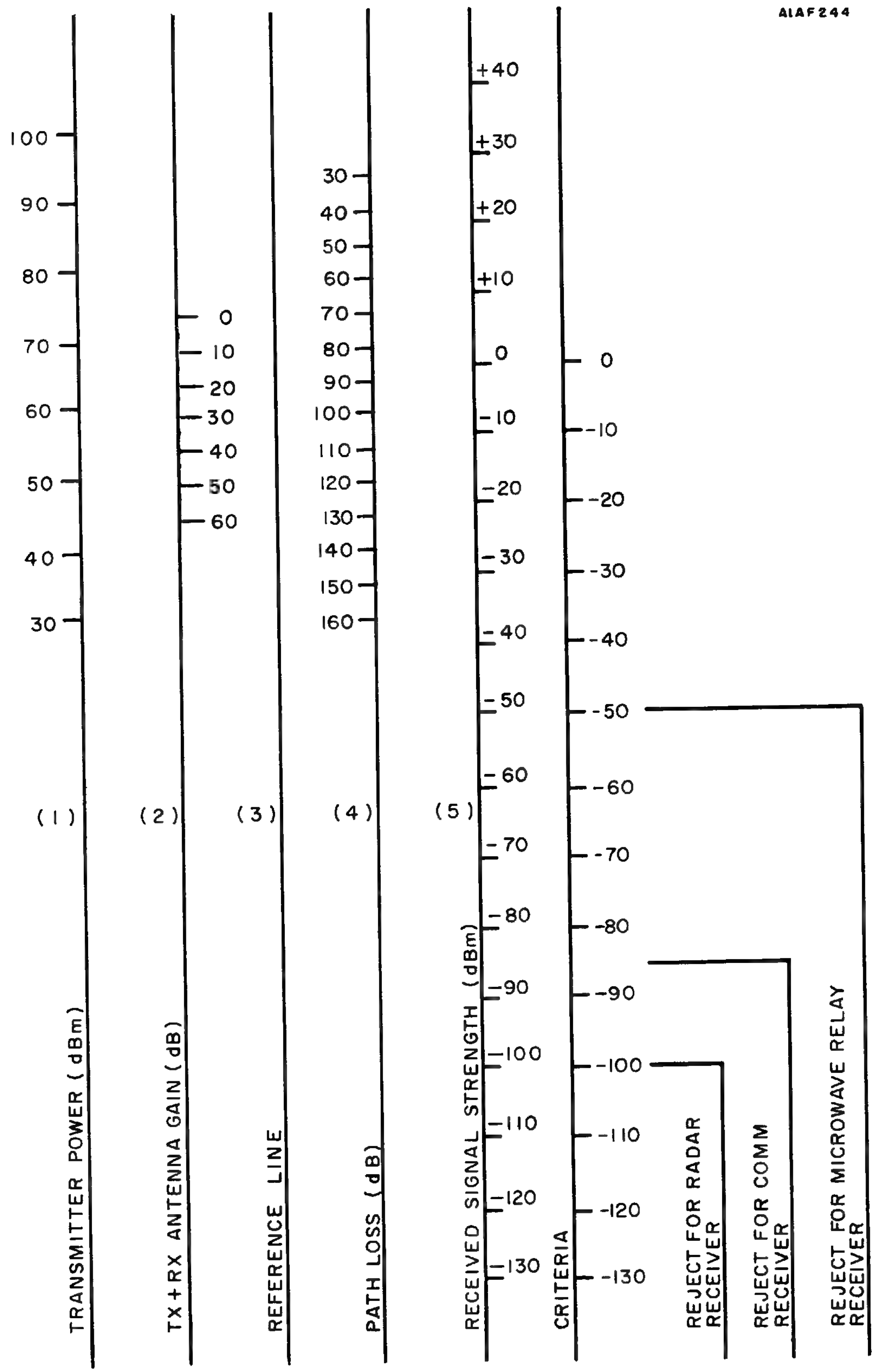

Figure 6 - 10. Nomogram for ERP Rapid Sorting

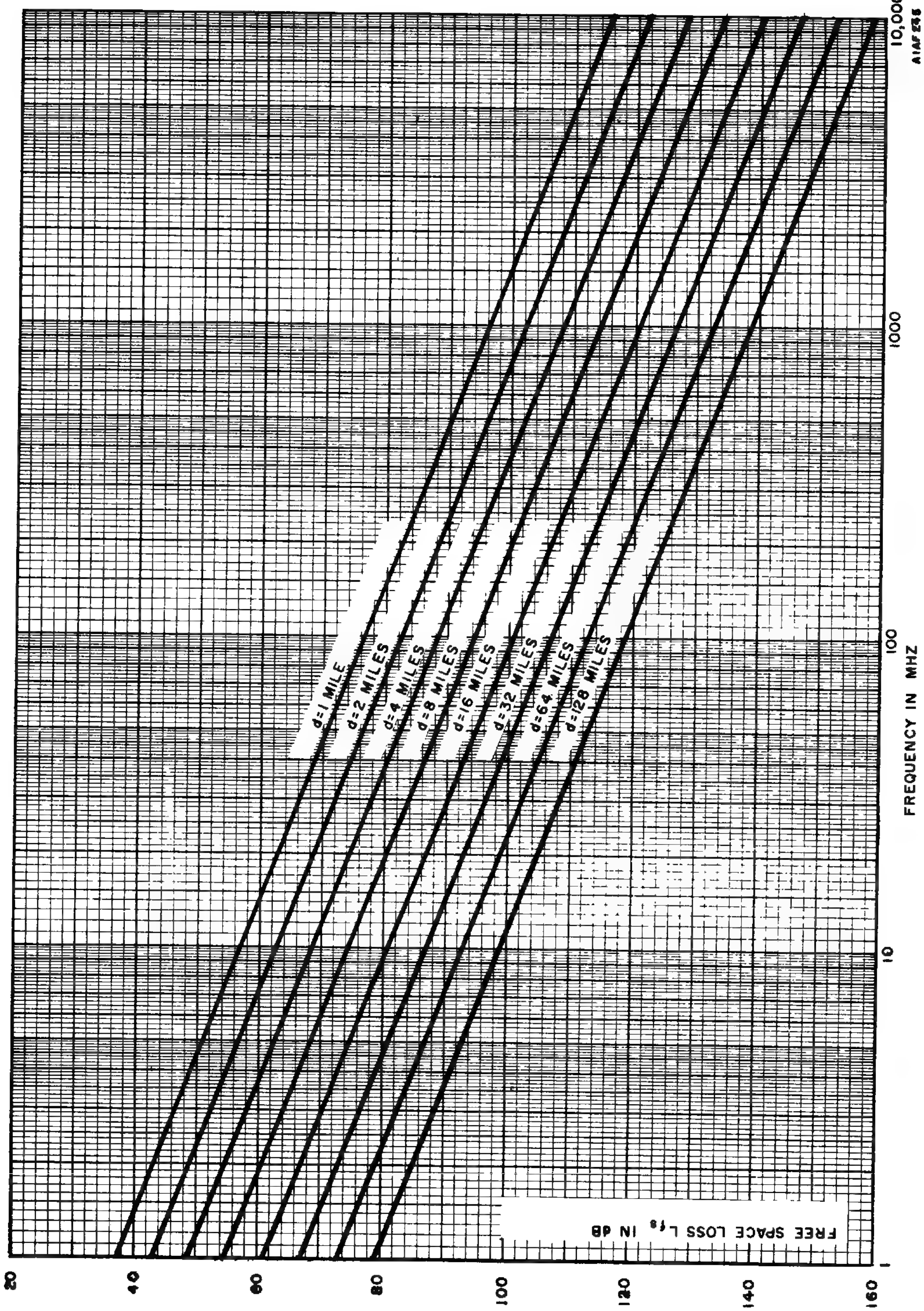

Figure 6 - 11. Free Space Propagation Loss

energy through the "standard atmosphere." The standard atmosphere is an atmosphere whose index of refraction varies linearly with height at a specific rate. The standard atmosphere is generally used for initial planning or site analysis since the composition and index of refraction of the actual atmosphere is a time-varying parameter, which is a function of season, temperature, moisture content, and other factors. It can be shown that the index of refraction for the standard atmosphere is such that if the curvature of the earth is represented as 4/3's its own radius (i.e., 4/3 x 3960 mi) the propagation rays emanating from an emitter, can be drawn as a straight line. Therefore, for convenience, 4/3 earth radius graph paper is used to analyze the propagation profiles involved in an interference analysis.

The RLOS for an emitter or radiated propagation over a smooth earth is limited by the point at which the ray is tangent to the earth. The region beyond this point (diffraction and/or scattering regions) is masked or obscured and receives little or no significant radiated power, insofar as geographical sorting is concerned.

In view of the short distances between equipments and the relatively flat terrain which is normally selected for a station, this method of sorting will have very limited application.

6.5 DISCRETE PREDICTION TECHNIQUES

Upon completion of the rapid sorting, the transmitters that have not been eliminated are considered likely sources of interference which require further analysis. Therefore, it is necessary to make a separate analysis of the relationships between each of these transmitters and the receiver under study.

This analysis consists of completing the calculation sheet whose entries cover transmitter, receiver, and propagation characteristics associated with each transmitter-receiver pair.

The EMI prediction formula readily lends itself to a ledger-sheet type of tabulation. Therefore, each of the variables is made an entry on the computation sheet shown in figure 6-1. Each of the entries in Columns "A" or "B" represents an operational condition associated with the potentially interfering transmitter-receiver pair being analyzed. Columns "C" and "D" are used either for totaling the values in Columns "A" and "B" or for inserting measured values of certain major parameters. Table 6-4 contains instructions identifying the data required for each line entry on the EMI prediction form. The table, together with the calculation sheet described herein and the referenced data sources, are all that is required to perform an EMI prediction calculation.

The top portion of the calculation sheet is simply a general information section, and as such, establishes the identity of the major elements of the particular prediction. Details of the individual sections are described in the following paragraphs.

6.5.1 Transmitter

This section presents the methods of calculating the effects of each of the transmitter system elements, i.e., transmitter power output, antenna gain and transmission line loss as they pertain to a potential interference situation. For the purposes of this report, transmitter systems have been arbitrarily classified as either radar or communications types.

The explanation of the individual transmitter entries is presented below.

o LINE 1.1, TX POWER (Fill in Radar TX or Communications TX Section)

This block of entries is used to calculate the amount of power being transmitted at the frequency of the interference. It is necessary to select and complete the appropriate portion of either the radar transmitter section or the communications transmitter section. The transmitter output power is a function of the transmitter frequency and quantitative description of the level, (i.e., watts, dBW, dBm). This information can be obtained from the manufacturer's specifications or operations manuals.

Table 6-4. Instructions for Making Entries in the EMI Prediction Calculation Sheet

REFERENCE ON CALCULATION SHEET LINE ENTRY AND SYMBOL	INSTRUCTIONS FOR DETERMINING DATA	DATA SOURCE
1. XMTR - identity	Standard AN nomenclature	C-E characteristics data sheet
2. RCVR - identity	Standard AN nomenclature	C-E characteristics data sheet
3. Code	This prediction number	
4. Date of form	Today's date	
5. XMTR and RCVR	Same as items 1 and 2	
6. XMTR site and RCVR site	Sites of items 1 and 2	Environmental characteristics form
Separation - R	Distance between items 1 and 2 statute miles	Environmental characteristics form
7. XMTR frequency f_t (MHz)	Operating frequency for item 1	C-E characteristics data sheet
RCVR frequency f_r (MHz)	Operating frequency for item 2	C-E characteristics data sheet
8. Frequency of interference -f_i (MHz)	A. Calculate harmonics of f_t - $2f_t, 3f_t, \ldots nf_t$	Not applicable
	B. At each frequency of interest, determine the frequency spread for: (1) XMTR emission spectrum $f_t, 2f_t, 3f_t, \ldots nf_t$ (2) RCVR selectivity response - f_r	C-E characteristics data sheet
	C. Determine whether (1) $f_r = f_t, 2f_t, 3f_t, \ldots nf_t$ (2) Any frequency in the spreads for XMTR [B(1)] falls in the spread for RCVR [B(2)]. The RCVR frequency that satisfies (1) or (2) is the item f_i	N/A
f_i is ________ function of f_t	Determine from "C" above $f_i = f_t, 2f_t, 3f_t, \ldots$ or nf_t or $f_i = f_t \pm \Delta f, 2f_t \pm \Delta f, \ldots$ or $nf_t \pm \Delta f$	N/A
9. XMTR antenna polarization	Horizontal, vertical, or other	C-E characteristics data sheet
RCVR antenna polarization	Horizontal, vertical, or other	C-E characteristics data sheet
10. Fundamental cochannel interference	If $f_i = f_t$ (item 8), determine	
	A. P_t (watts)	C-E characteristics data sheet
	B. $(10 \log P_t) + 30$ (+dBm)	N/A
11. Fundamental adjacent channel interference	If $f_i = f_t \pm \Delta f$ (item 8), determine	
	$(10 \log P_t) + 30$ (+dBm) as in item 10	N/A
12. (Δf = off-center frequency - MHz)	Find τ = pulse width (μsec)	C-E characteristics data sheet
	Calculate $40 \log \pi\tau\Delta f$ (−dB)	N/A
	Find T_r = pulse rise time (μsec)	C-E characteristics if available
	T_f = pulse fall time (μsec)	C-E characteristics if available
	Calculate $k = \frac{T_r + T_f}{2\tau}$ and $20 \log k$(-dB)	If T_r and T_f not available use K = 0.1
12. and 13. Alternate	For Δf and selected k (=0.1), read power correction (-dB) in Figure 6-13	

Table 6-4. Instructions for Entries in the EMI Prediction Calculation Sheet (Continued)

REFERENCE ON CALCULATION SHEET LINE ENTRY AND SYMBOL	INSTRUCTIONS FOR DETERMINING DATA	DATA SOURCE
14. Harmonic cochannel interference	A. (10 log P_t +30 (+dBm) as in item 10	N/A
15. dB down from f_o	B. Value of n	N/A
	C. dB down due to harmonic roll-off for value of n	Characteristics sheet or Table 6-5
16. Harmonic adjacent channel interference	If $f_i = hf_t \pm \Delta f$ (item 8) determine	
	A. (10 log P_t) + 30 (+dBm) as in item 10	N/A
17. (Δf = off-center frequency MHz)	B. dB down as in item 15C	Same as item 15 C
	C. 40 log $\pi\Delta f$ (-dB) as in item 12	Same as item 12
	D. 20 log K (-dB) as in item 13	Same as item 13
18. and 19 alternate	Same as items 12 and 13 alternate	Figure 6-13
20. Same as item 10 for a communication XMTR		
21. Same as item 14 for a communications XMTR		
22. Same as item 15 for a communications XMTR		
23. XMTR transmission line loss - L_t (-dB)	Calculate $L = L\alpha$ where L = total line length (in 100') α = attenuation/100'	Figures 6-14, 6-15
	Add to L other RF component losses, which are known or can be estimated, to obtain L_t (-dB). If undeterminable, use	N/A
	L_t = 2 dB.	N/A
24. XMTR antenna gain	Nominal gain (+dB)	C-E characteristics data sheet or figure 6-16 and 6-17
25. Loss due to off-axis pointing	Determine antenna beamwidth, b^o Determine antenna misalignment between XMTR and RCVR in degrees and in number of antenna beamwidths. Determine loss (-dB)	C-E characteristics data sheet
26. Loss due to near field effect = C_{FR} (-dB)	Determine Fresnel boundary distance (d_{min})	Figure 6-22
	If R (item 6) $< d_{min}$, calculate x and y	Figure 6-23
	Read C_x and C_y, page from figure 6-23. Find $C_{FR} = C_x + C_y$ (-dB)	N/A
27. Subtotal, column A	Add + dB in column A for XMTR	N/A
28. Subtotal, column B	Add -dB in column B for XMTR	N/A
29. Total, item 27 - item 28	Subtract to obtain ERP in dBm and enter in column C (+) or D(-)	
30. Wave spreading	For R (item 6), determine loss (-dB)	Figure 6-25
31. Reflection field loss = A (-dB)	Calculate A (-dB) by using figure 6-26	Figure 6-26
32. Diffraction field loss = D (-dB)	N/A	N/A
33. Scatter field	N/A	N/A
34. Subtotal, column A	Add + dB in column A for propagation	N/A
35. Subtotal, column B	Add - dB in column B for propagation	N/A
36. Total, item 34 - item 35	Subtract to obtain propagation losses in dB and enter in column D(-)	N/A
37. Power density at RCVR, item 29 - item 36	Subract to obtain power density at the RCVR site (dBm/m^2/ MHz)	N/A
38. Loss due to polarization mismatch	Use item 9 to determine loss (dB)	Table 6-9
39. RCVR effective area	If A_R is known, compute 10 log A_R (dB)	
40. RCVR frequency	If A_R is not known, read 20 log f from figure 6-34(-dB)	Figure 6-34

Table 6-4. Instructions for Entries in the EMI Prediction Calculation Sheet (Continued)

REFERENCE ON CALCULATION SHEET LINE ENTRY AND SYMBOL	INSTRUCTIONS FOR DETERMINING DATA	DATA SOURCE
41. RCVR antenna gain	Repeat item 24 for RCVR (+dB)	Same as item 24
42. Loss due to off-axis pointing	Repeat item 25 for RCVR (-dB)	Same as item 25
43. Loss due to near field effect	Repeat item 26 for RCVR (-dB)	Same as item 26
44. RCVR transmission line loss - L_R (-dB)	Repeat item 23 for RCVR	Same as item 23
45. Subtotal, column A	Add +dB column A for items 39-41 + 38.6 dB	N/A
46. Subtotal, column B	Add - dB in column B for items 38, 39, 40, 42, 43, and 44	N/A
47. Total, item 45 - item 46	Subtract to obtain RCVR transfer effect in and enter in column C (+) or D(-)	N/A
48. RCVR interference power, item 37 ± item 47	Add or subtract to obtain power at RCVR input terminals in dBm and enter in column C(+) or D(-)	N/A
49. Fundamental cochannel interference	If $BW_{RCVR} < \frac{2}{T}$ calculate 10 log (0.5 BW_{RCVR}) (dB)	C-E characteristics data sheet
50. Fundamental adjacent channel interference	Calculate 10 log (BW_{RCVR}) (dB)	C-E characteristics data sheet
51. Harmonic cochannel interference	If $BW_{RCVR} < \frac{2}{T}$, calculate 10 log (0.5 BW_{RCVR}) (dB)	C-E characteristics data sheet
52. Harmonic adjacent channel interference	Calculate 10 log (BW_{RCVR}) (dB)	C-E characteristics data sheet
53. 10 log (BW_{RCVR})	Same as item 50 (dB)	C-E characteristics data sheet
54. 10 log (BW_{RCVR})	Calculate for communications XMTR (dB)	C-E characteristics data sheet
55. RCVR sensitivity (-dBm)	Determine from spec. data or calculate in accordance with figure 6-37	C-E characteristics data sheet
56. Subtotal, column A	Add + dB in column A for items 49-55	N/A
57. Subtotal, column B	Add - dB in column B for items 49-54	N/A
58. Total, item 56 - item 57	Subract to obtain adjusted RCVR threshold and enter in column C(+dBm) or D (-dBm)	N/A
59. $\frac{I}{N}$ Ratio, item 48 + item 58	Add algebraically (watching all signs) to obtain effective interference power at RCVR input terminals referenced to adjusted RCVR threshold in dB and enter in column C(+) or D(-)	N/A
60. Assumed or known RCVR $\frac{S}{N}$ (+dB)	If RCVR $\frac{S}{N}$ is known, enter in column C. If RCVR $\frac{S}{N}$ is not known, estimate or calculate value using equation 27, and table 6-10	C-E characteristics data sheet
61. Predicted $\frac{S}{I}$ item 60 - item 59	If item 59 >0, subtract and enter in column C (+) or D(-)	N/A

o Radar Transmitters

o LINE 1.1.1, FUNDAMENTAL COCHANNEL INTERFERENCE ($f_r = f_t$)

The amount of power transmitted (P_t) is assumed to be the full rated power of the radar unless known otherwise. For multibeam radars, this is the power delivered to the lower antenna beam. For example, if a one megawatt radar is being considered, Line 1.1.1.1 becomes ($10 \log 1 \times 10^6$) + 30 = 90 dBm. Thus, for this case, the transmitted power level is 90 dBm.

o LINE 1.1.2, FUNDAMENTAL ADJACENT CHANNEL INTERFERENCE

In this case, the amount of power existing at some frequency adjacent to the carrier frequency becomes a function of the transmitter modulation side band power density distribution (P_{tr}). The P_{tr} of a typical radar is shown in figure 6-12. This distribution is a function of the characteristics of the modulating pulse. The amount of power existing at a specific frequency within this distribution may be calculated by assuming that the full rated power exists (line 1.1.2.1) and then modifying this accordingly (lines 1.1.2.2 and 1.1.2.3).

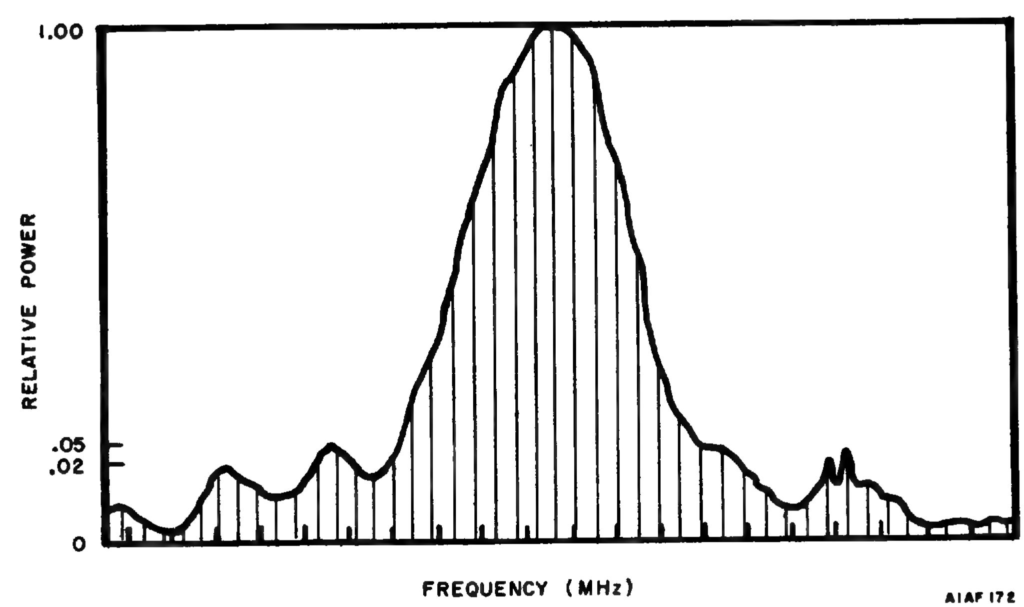

Figure 6 - 12. Sideband Power Density Distribution

o LINE 1.1.2.1, (10 log P_t) + 30 (See discussion of Line 1.1.1.1)

o LINES 1.1.2.2 -40 log ($\pi\tau\Delta f_{MHz}$) and 1.1.2.3 -20 log K

These entries represent the necessary modifying factors for transmitted power of a rectangular pulsed radar for case 1.1.2. Since in any real situation no pulse has zero rise time, these rectangular pulses resemble trapezoids. If K is now defined as representing the pulse shape, factor then P_{tr} for a pulsed radar may be stated as an equation, thusly:

$$10 \log P_{tr} = 10 \log P_t - 20 \log K - 40 \log \pi\tau\Delta f_{MHz} \tag{6-5}$$

where:

$$K = \frac{T_r + T_f}{2\tau} \quad \text{in similar units e.g., msec, } \mu\text{sec, etc.}$$

When K cannot be determined for a selected radar, a value of 0.1 should be used. As can be seen, Lines 1.1.2.2 and 1.1.2.3 represent Equation 6-5 and should only be filled in if the radar transmitter in question is a trapezoidal pulse modulated radar. Figure 6-13 represents the distribution of the side bands for pulse modulation. The pulse can have a rectangular, trapezoidal, cosine or cosine squared shape. Consequently, for these pulse shapes, P_{tr} can be determined directly from figure 6-13 and inserted in Column B in lieu of Lines 1.1.2.2 and 1.1.2.3.

o LINES 1.1.3, HARMONIC COCHANNEL INTERFERENCE and 1.1.4, HARMONIC ADJACENT CHANNEL INTERFERENCE

These harmonic cases directly parallel their fundamental frequency counterparts with the exception that the additional dB suppression of the harmonic peak from the fundamental is added. While these harmonics can be modeled theoretically, their existence and level cannot be predicted with very much accuracy. Therefore, it is necessary to use empirical data for the radar harmonic emissions. This information may be obtained from the manufacturer or from manuals for the radar in question. Where specific harmonic levels are not available for a certain radar, the values shown in table 6-5 may be used.

Table 6-5. Harmonic Levels of Communications and Radar Equipment

RELATIVE TRANSMITTER POWER OUTPUT FROM COMMUNICATIONS EQUIPMENT AND ERP OF RADARS (IN UNITS OF dB BELOW FUNDAMENTAL)				
Harmonic Number	Communications			Radar
	AM	FM	SSB	
2	49	67	56	48
3	65	77	81	57
4	76	76	87	62
5	80	79	93	66
6	82	78	88	68
7	82	82	90	72
8	83	81	88	74
9	87	85	90	76
10	85	84	90	78

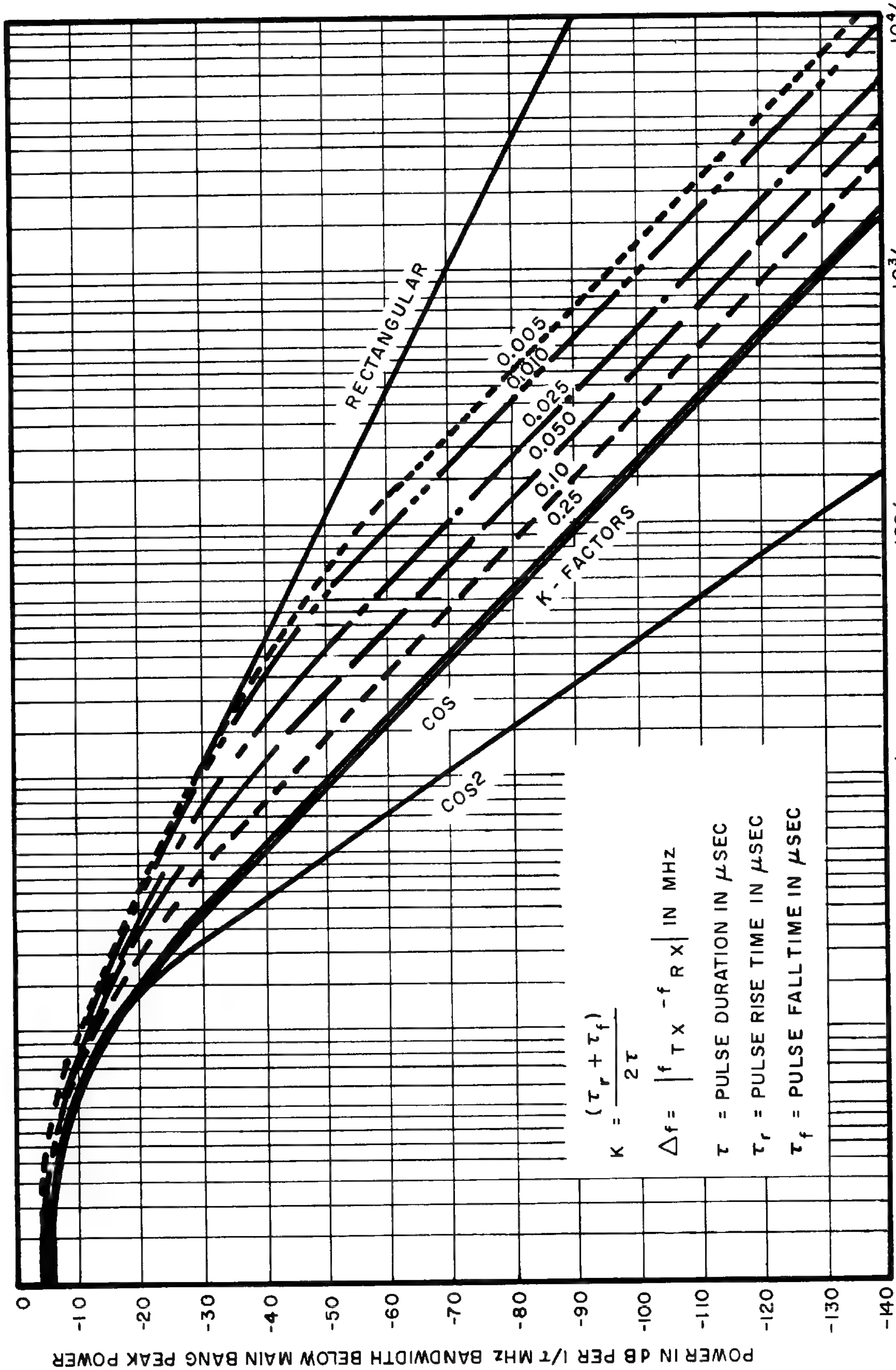

Figure 6-13. Transmitter Power Spectral Density vs. Off-Frequency Displacement for Pulse Modulated Signals

o Communications Transmitters

Interference from a communications transmitter is assumed to exist in this report only when one of the following two situations exists: (1) the communications transmitter and the subject receiver are operating at the same frequency, i.e., fundamental cochannel interference; or (2) the receiver is operating at a frequency which is a harmonic of the transmitter.

o LINE 1.1.5, FUNDAMENTAL COCHANNEL INTERFERENCE ($f_r = f_t$) See discussion under 1.1.1

o LINE 1.1.6, HARMONIC COCHANNEL INTERFERENCE See discussion under 1.1.3

o LINE 1.2, TX TRANSMISSION LINE LOSS, L_t (dB)

Unless otherwise known, this entry is an engineering estimate based on the attenuation of the transmission line per unit length, the length of transmission line, the number of butt and/or flange joints, and the transmission loss of components such as rotary joints, (TR) switches and suppression filters. Figure 6-14 shows the attenuation in dB per 100 feet for various types of waveguides. Figure 6-15 shows the attenuation in dB per foot versus operating frequency for various types of RF cables. When the measured ERP is used as a basis for determining the transmitting power, the transmission line loss in Line 1.2 is set equal to zero, since it is already contained in the ERP.

o LINE 1.3, TX ANTENNA GAIN, G_t (dB)

This entry represents the transmitter directional antenna gain expressed in dB above isotropic. In a cochannel or adjacent channel situation where both the transmitting and the receiving antennas are located in the far field of each other, and where the antenna beams are pointing at each other (if applicable), the rated or nominal gain of each antenna applies. However, this optimum situation frequently does not prevail, such as: (1) in cases where one or both of the C-E equipments have scanning antennas, (2) where one of the equipments is a microwave relay link, (3) where the equipments are collocated at the same physical site, and (4) where the transmitting and receiving equipments operate at substantially different frequencies. Under these and other situations, the following gain correction factors have been included on the form shown in Figure 6-1 and are completed where applicable: off-axis antenna beam pointing losses, and near-field defocusing effects.

If the antenna gain is not available, it may be estimated by:

$$G_t = \frac{27{,}000}{\Theta_h \Theta_v} \qquad (6\text{-}6)$$

where:

G_t = the numerical gain of the antenna

Θ_h = horizontal beamwidth of the antenna in degrees

Θ_v = vertical beamwidth of the antenna in degrees

Equation 6-6 has been solved and plotted as a nomogram in Figure 6-16. If, however, the antenna beamwidths are not known, they may be determined by using equation:

$$\Theta^\circ = \frac{70\lambda}{d} \qquad (6\text{-}7)$$

where:

λ = the wavelength at the frequency at which the antenna is being operated

d = the dimension of the antenna in the h or v direction, as applicable.

A-N TYPE	MATES WITH FLANGE Cover	MATES WITH FLANGE Choke	MATE-RIAL	INTERNAL DIMENSIONS	RECOMMENDED OPERATING RANGE TE_{10} MODE Frequency kmc/sec	Wavelength Air cm	Wavelength Guide cm	Wavelength Guide in	CUTOFF Freq. KMHz	CUTOFF Wave-length cm	CALC ATTEN db/100 ft. Low Freq.	CALC ATTEN db/100 ft. High Freq.	CALC MAX cw Power Megawatts Low Freq.	CALC MAX cw Power Megawatts High Freq.
RG 69/U RG 103/U	UG-417A/U UG-417A/U	UG-417A/U UG-417A/U	Brass Alum.	6.500x3.250	1.12- 1.70	26.766-17.634	45.706-20.857	17.994-8.212	.908	33.020	.424 .269	.284 .178	11.9	17.2
RG 104/U RG 105/U	UG-435A/U UG-437A/U	UG-435A/U UG-437A/U	Brass Alum.	4.300x2.150	1.70- 2.60	17.634-11.530	29.878-13.575	11.763-5.344	1.372	21.844	.788 .501	.516 .330	5.2	7.5
RG 112/U RG 113/U	UG-553/U UG-554/U	UG-553/U UG-554/U	Brass Alum.	3.400x1.700	2.20- 3.30	13.626- 9.084	22.175-10.681	8.730-4.205	1.736	17.272	.877 .751	.572 .492	3.5	4.7
RG 48/U RG 75/U	UG-53/U UG-584/U	UG-54A/U UG-585/U	Brass Alum.	2.840x1.340	2.60- 3.95	11.530- 7.589	19.181- 8.924	7.552-3.513	2.078	14.427	1.48 .940	1.01 .641	2.2	3.2
RG 49/U RG 95/U	UG-149A/U UG-407/U	UG-148B/U UG-406A/U	Brass Alum.	1.872x0.872	3.95- 5.85	7.589- 5.124	12.594- 6.083	4.958-2.395	3.152	9.510	2.79 1.77	1.93 1.22	1.4	2.0
RG 50/U RG 106/U	UG-344/U UG-441/U	UG-343A/U UG-440A/U	Brass Alum.	1.372x0.622	5.85- 8.20	5.124- 3 656	7.560- 4.294	2.976-1.691	4.301	6.970	3.85 2.45	3.08 1.94	.56	.71
RG 51/U RG 68/U	UG-51/U UG-138/U	UG-52A/U UG-137A/U	Brass Alum.	1.122x0.497	7.05-10.00	4.252- 2.998	6.385- 3.525	2.514-1.388	5.259	5.700	5.51 3.50	4.31 2.74	.35	.46
RG 52/U RG 67/U	UG-39/U UG-135/U	UG-40A/U UG-136A/U	Brass Alum.	0.900x0.400	8.20-12.40	3.656- 2.418	6.088- 2.848	2.397-1.121	6.557	4.572	8.64 5.49	6.02 3.83	.20	.29
RG 91/U RG 107/U	UG-419/U UG-419/U	UG-541/U UG-541/U	Brass Silver	0.622x0.311	12.40-18.00	2.418- 1.665	3.754- 1.960	1.478- .772	9.487	3.160	12.8 6.14	11.2 5.36	.12	.16
RG 53/U RG 121/U RG 66/U	UG-595/U UG-597/U UG-595/U	UG-596/U UG-598/U UG-596/U	Brass Alum. Silver	0.420x0.170	18.00-26.50	1.665- 1.131	2.664- 1.334	1.049- .525	14.048	2.134	27.7 17.6 13.3	19.8 12.6 9.50	.043	.058
RG 96/U	UG-599/U	UG-600/U	Silver	0.280x0.140	26.50-40.00	1.131- .749	1.866- .882	.735- .347	21.075	1.422	21.9	15.0	.022	.031
RG 97/U	UG-383/U	UG-383/U	Silver	0.224x0.112	33.00-50.00	.909- .600	1.508- .705	.549- .278	26.342	1.138	31.0	20.9	.014	.020
RG 98/U	UG-385/U	UG-385/U	Silver	0.148x0.074	50.00-75.00	.600- .400	.994- .472	.391- .186	39.864	.752	52.9	39.1	.0063	.0090
RG 99/U	UG-387/U	UG-387/U	Silver	0.122x0.061	60.00-90.00	.500- .333	.844- .395	.332- .156	48.351	.620	93.3	52.2	.0042	.0063

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Figure 6 - 14. Standard Waveguide Characteristics

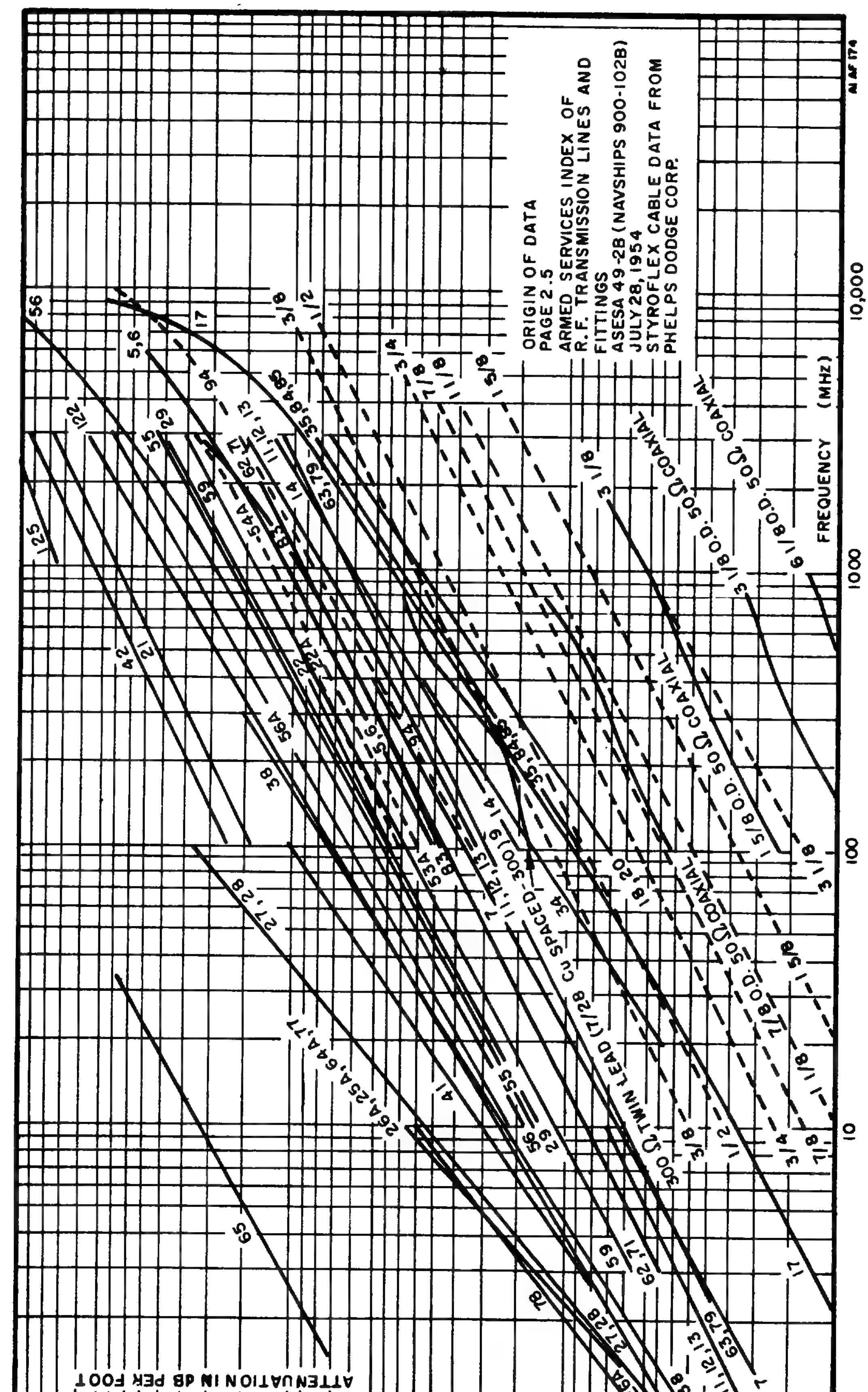


Figure 6-15. Attenuation of Standard RF Cables vs. Frequency (MHz)

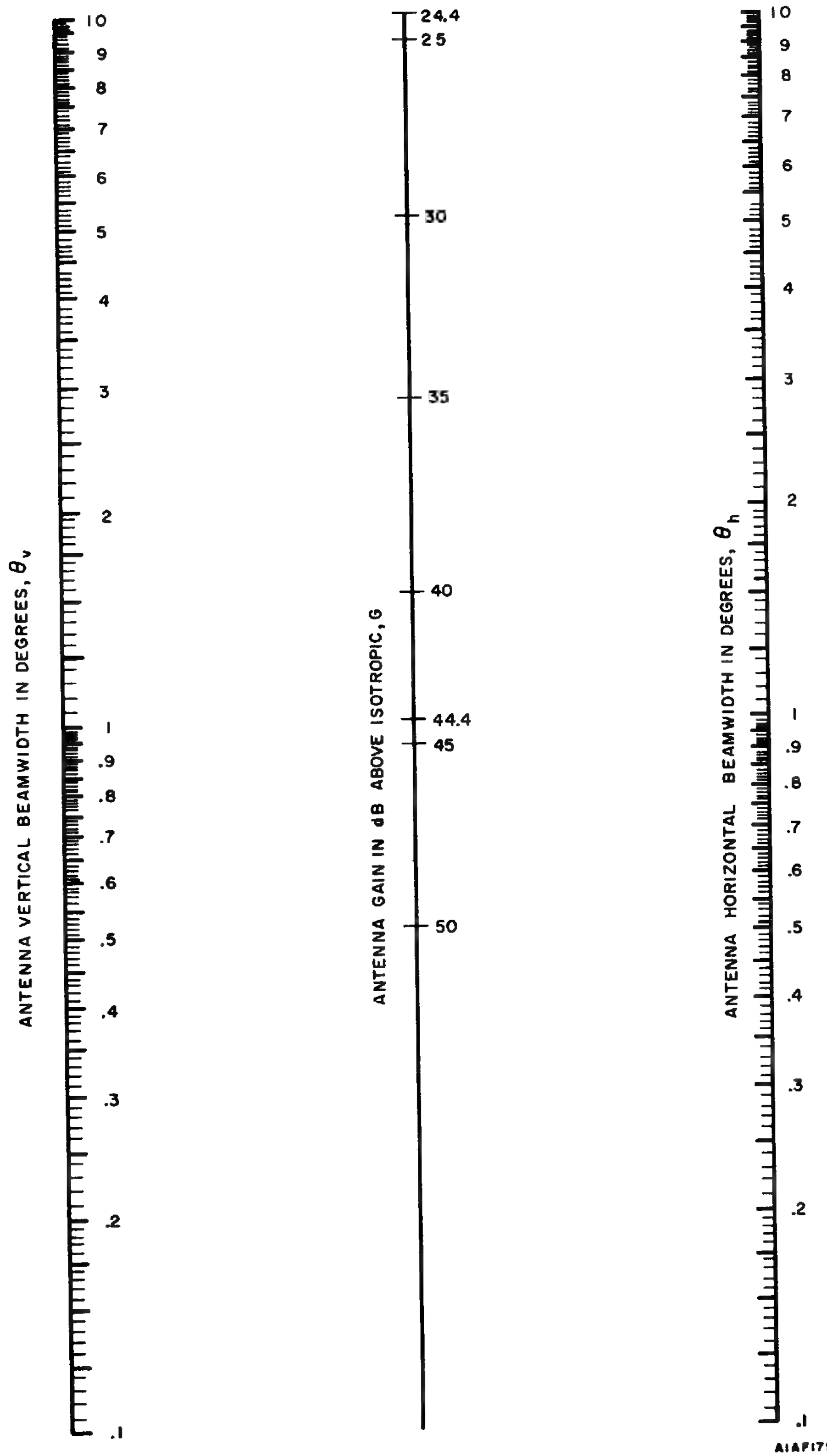


Figure 6 - 16. Nomogram for Determining Antenna Gain

Equation (6-7) has been plotted in Figure 6-17 as a nomogram.

o LINE 1.3.1, LOSS DUE TO OFF-AXIS POINTING AT RX

The case of two horizon scanning radar antennas is solved for the most pessimistic EMI situation, viz, the two antennas "looking at" each other or otherwise representing the angle of closest approach. If vertical misalignment of antenna exit or entry angle exists with the boresight axis and this value is greater than the one-half vertical beamwidth, obtain the correction from vertical pattern data. Consider the gain of either antenna to be 0 dB in any situation other than within a wedged sector representing twice the horizontal and vertical beamwidth, unless empirical data are otherwise available.

A somewhat different approach is required for the case of fixed antenna (non-scanning type) installations such as at microwave relay links. Since the first calculations are based on the most pessimistic situation, the orientation of a scanning radar antenna is chosen to give the minimum off-axis orientation with respect to the fixed antenna. The loss due to both horizontal and vertical off-axis pointing of the fixed antenna installation is obtained from published antenna polar plots or by assuming the loss from tables of nominal directional gain for different antenna types. If this is not available, then the gain corrections must be obtained by other methods, including choosing a known standard antenna type most closely resembling the one in question. The following discussion presents the methods for correcting for both horizontal and vertical off-axis antenna beam pointing.

o OFF-AXIS HORIZONTAL ANTENNA GAIN CORRECTION

While it is recommended that horizontal polar plot data corresponding to the specific antenna being analyzed be used, such data are not always available. For high gain antennas ($G \geqslant 10$ dB) Figure 6-18 can be used to obtain an approximate correction for horizontal off-axis situations.

Since the completion of data of Figure 6-1 is based on the most pessimistic EMI situation, it is assumed that a scanning antenna is horizontally aligned with the other C-E equipment (emphasis on search and height finder radars) unless this situation cannot possibly prevail (e.g. tracking radar or telemetry). If the latter applies, the entry in the abscissa of Figure 6-18 is made at the off-axis angle in degrees corresponding to the number of horizontal beamwidths. The ordinate of Figure 6-18 thus corresponds to the resulting horizontal gain correction. If the off-axis angle is significant (e.g., >5 beamwidths) the horizontal gain correction is such that the resulting antenna gain should not be less than -10 dB. In any event, the gain correction should not be such that an over-all antenna gain of less than -10 dB with reference to an isotropic radiator is realized. This value corresponds to a typical scatter level gain for scanning type antennas.

Where antennas used in microwave relay links are involved, specific horizontal polar plot data are usually available and should be used for off-axis horizontal gain corrections. For those situations where a substantial horizontal off-axis antenna pointing situation may exist, it is possible that the directional gain may be less than -10 dB. A lower limit of -25 dB above isotropic is assumed to apply.

o OFF-AXIS VERTICAL ANTENNA GAIN CORRECTION

The correction required for a vertical angle antenna beam misalignment between the transmitting and receiving pair involves calculations similar to that for horizontal, plus other considerations: corrections for the vertical angle displacement between antenna electrical pointing axis and tangent to the earth; corrections for separation distance between antennas resulting in corrections due to curvature of the earth; and corrections for difference in antenna elevations above mean sea level (MSL). These additional corrections result in an over-all vertical entry or exit angle correction that must be made for high gain antennas whose beams are not pointing at each other. The following discussion amplifies these considerations.

The vertical entry or exit angle Φ between the antenna axis and the arriving or departing wave, may be computed with reference to Figures 6-19 and 6-20.

$$\Phi = \alpha + \beta + \gamma \tag{6-8}$$

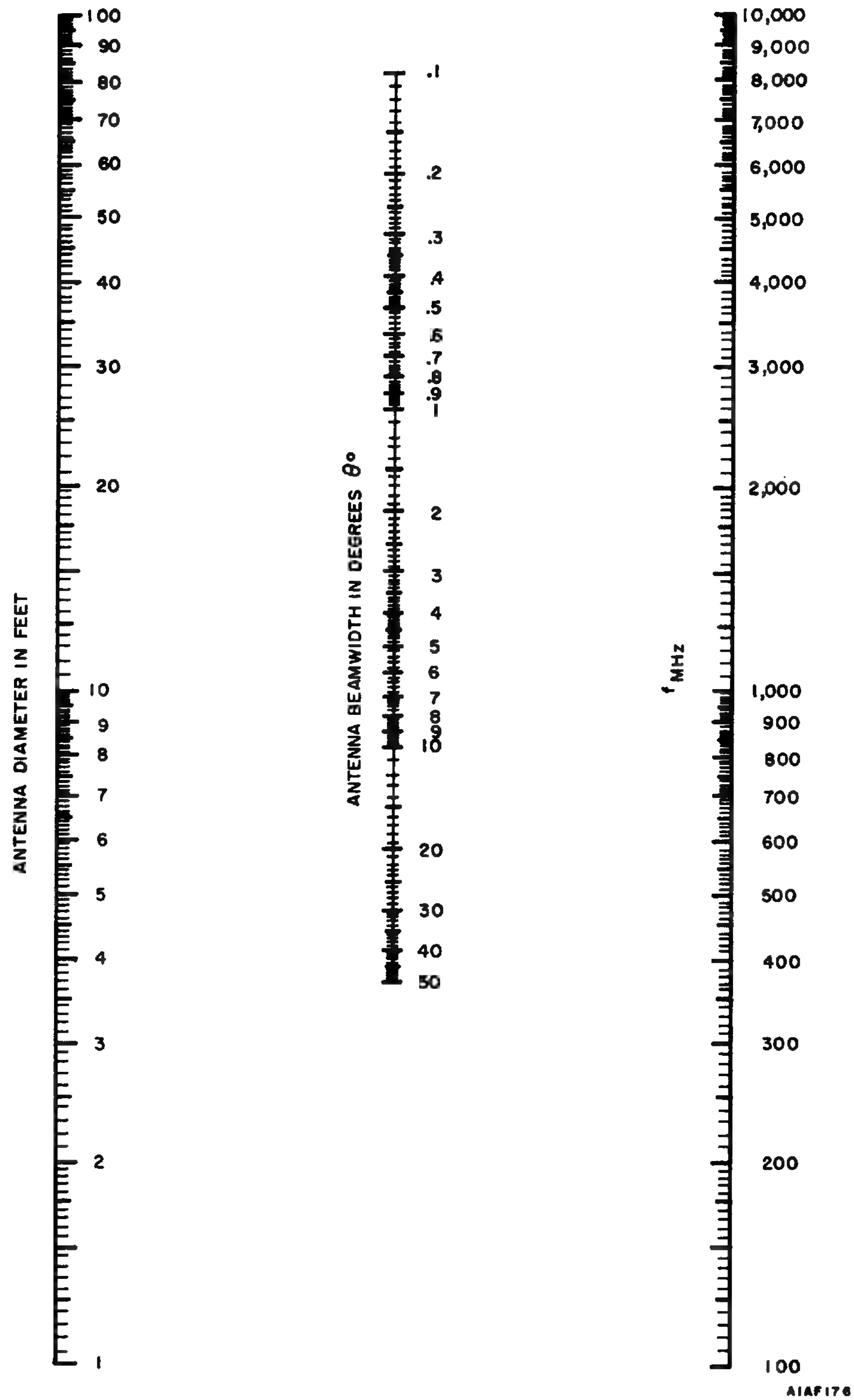


Figure 6 - 17. Nomogram for Determining Antenna Beamwidth

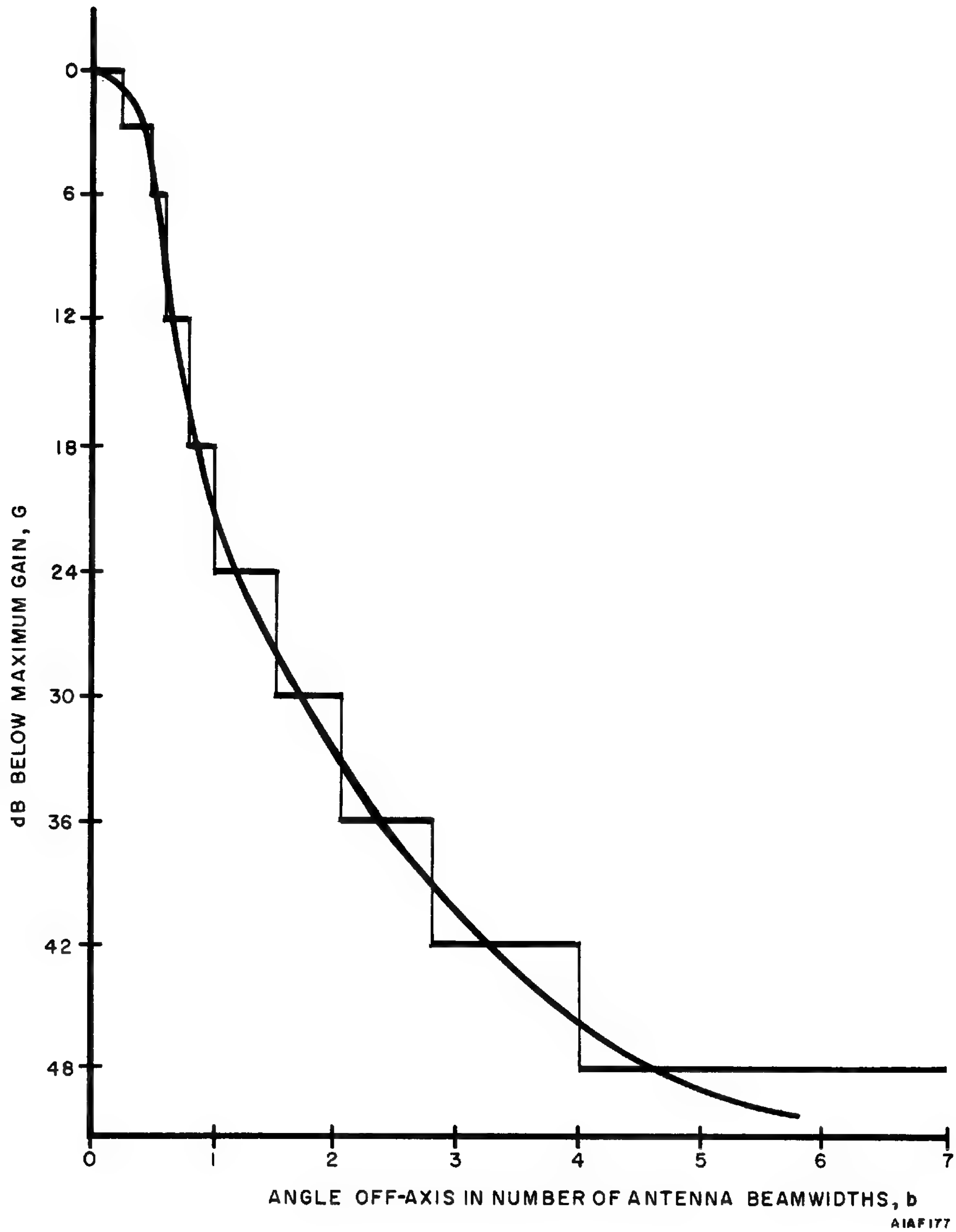


Figure 6 - 18. Envelope and Quantization of Typical High Gain Antenna Pattern

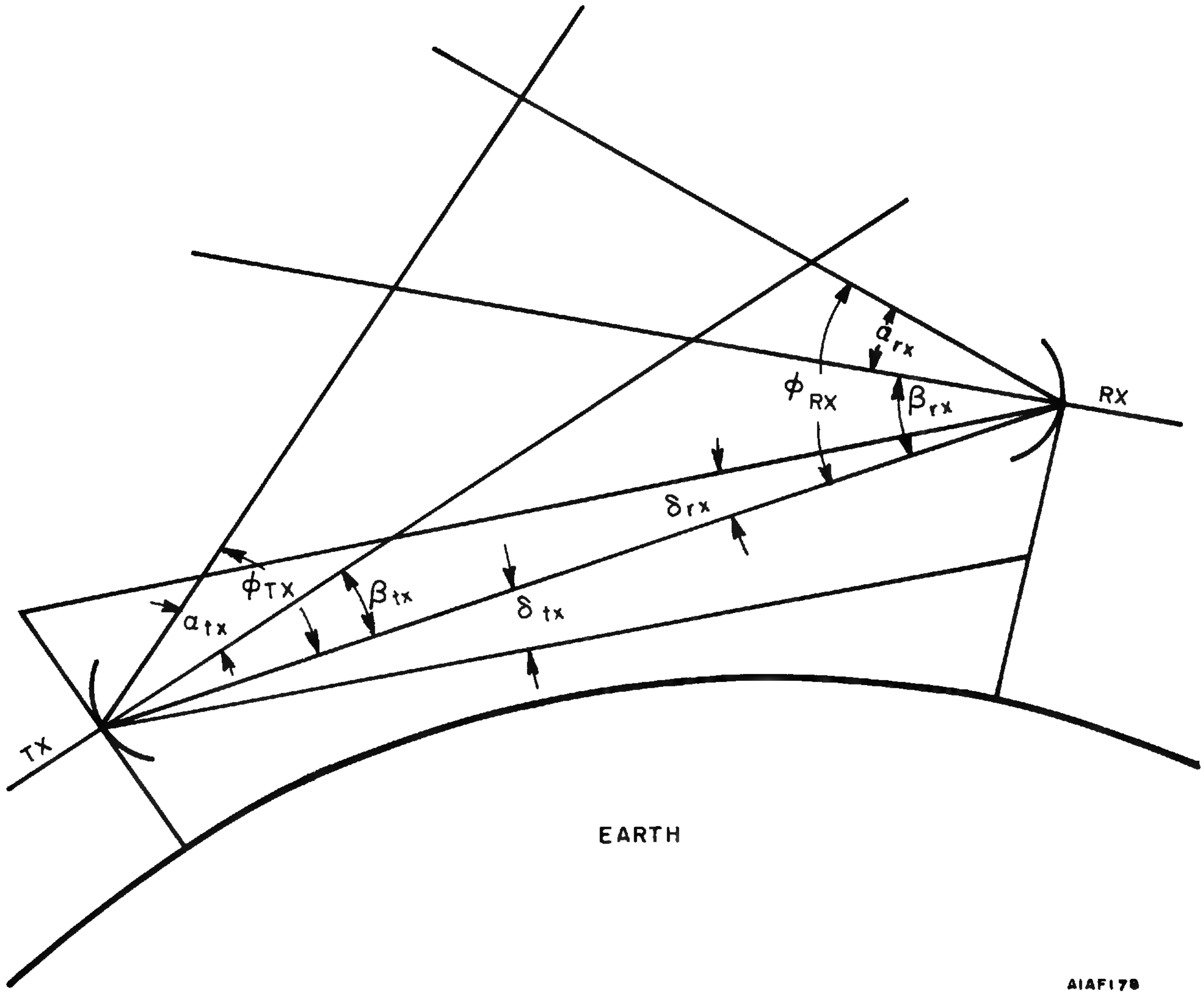


Figure 6-19. Exit and Entry Elevation Angle Situation Between TX-RX Pairs

where:

α = elevation angle between antenna axis and the tangent to the earth

β = elevation angle due to curvature of the earth

γ = elevation angle due to difference between TX-RX antenna elevations above MSL.

In terms of each of the above separate elevation angles, Φ may be computed for either TX or RX.

$$\Phi_{TX}=\alpha_{TX}+0.0073R_{mi}-0.0109(h_{RX}-h_{TX})/R_{mi}\text{degrees} \tag{6-9}$$

$$\Phi_{RX}=\alpha_{RX}+0.0073R_{mi}+0.0109(h_{RX}-h_{TX})/R_{mi}\text{degrees} \tag{6-10}$$

where:

Φ = the total off-axis vertical entry or exit angle in degrees

R_{mi} is the TX-RX distance (in statute miles)

h_{RX} is the height (in feet) above MSL of the RX antenna

h_{TX} is the height (in feet) above MSL of the TX antenna

Figure 6-19 depicts the details of the individual elevation angle corrections defined in equations 6-9 and 6-10. The third term of these equations is an approximation since the heights of the antennas are foreshortened by the cosine of the earth curvature (see figure 6-20). For distances corresponding to angles less than about ten degrees (TX-RX separation of 800 miles), the error is negligible.

The α and the γ terms are the prime contributors to antenna off-axis entry or exit angles. The α term must be determined at the site. The γ term becomes large if both the difference between the TX and RX antennas' height above MSL is large and the physical separation is small.

After computing the total off-axis vertical entry or exit angle in degrees, it remains to determine the resulting antenna gain correction. As used for horizontal gain correction, known vertical pattern data must be used. If this is not available, see figure 6-18 for high gain antennas. If the vertical pattern is of cosecant$^2\Theta$ type (e.g. many search radar antennas) figure 6-21 may be used. Where microwave relay links and high gain antennas other than those used for radar are involved, the vertical antenna gain corrections shown in table 6-6 may be used.

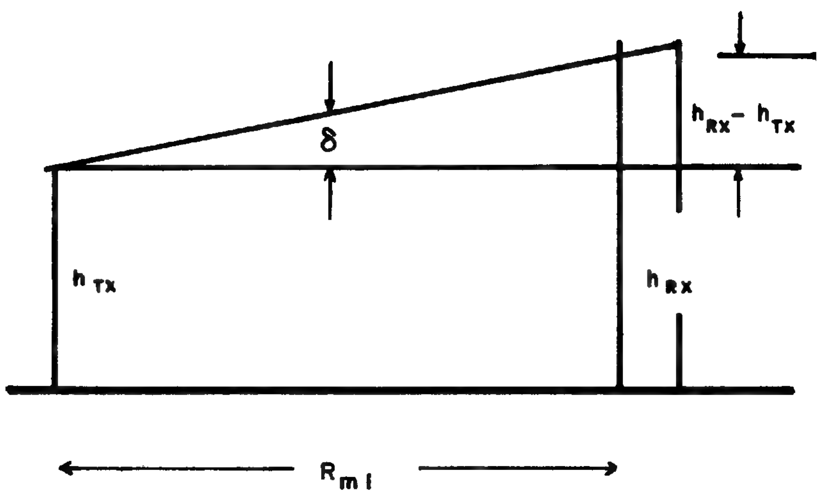
o LINE 1.3.2, LOSS DUE TO NEAR FIELD EFFECT

When either the transmitting or receiving antenna is in the Fresnel region of the other, an antenna gain correction factor must be applied to the far field in order to present a realistic situation. No correction is required, however, for low gain antennas (less than 10 dB). In order to determine the exact boundary between the Fresnel region and the far-field, equation 6-11 may be used. If it is necessary to determine whether a Fresnel situation exists, or not, figure 6-22 should be consulted.

$$d_{min} = \frac{L^2 f_{MHz}}{984} \tag{6-11}$$

Table 6-6. Typical Quantized Vertical Antenna Gain Used in Microwave Relay Links

VERTICAL OFF-AXIS ENTRY ANGLE	GAIN
$-B_v/2 \leqslant \phi_v \leqslant B_v/2$	G_{RX}
$-B_v/2 \leqslant \phi_v < -B_v/2$ $B_v/2 < \phi_v \leqslant B_v$	G_{RX} - 10 dB
$-2B_v \leqslant \phi_v < -B_v$ $B_v < \phi_v \leqslant 2B_v$	G_{RX} - 25 dB
Other entry angles	G_{RX} - 60 dB
where: ϕ_v = interference signal entry angle B_v = vertical 3 dB beamwidth G_{RX} = receiver antenna gain in dB	



$$\tan \delta = \frac{(h_{RX} - h_{TX})}{5280\, R_{mi}}$$

$$\delta = \frac{57.3\,(h_{RX} - h_{TX})}{5280\, R_{mi}}$$

$$= 0.0109\ (h_{RX} - h_{TX})/R_{mi}\ \text{DEGREES}$$

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Figure 6 - 20. Correction per Difference in TX-RX Antenna Elevation Above MSL

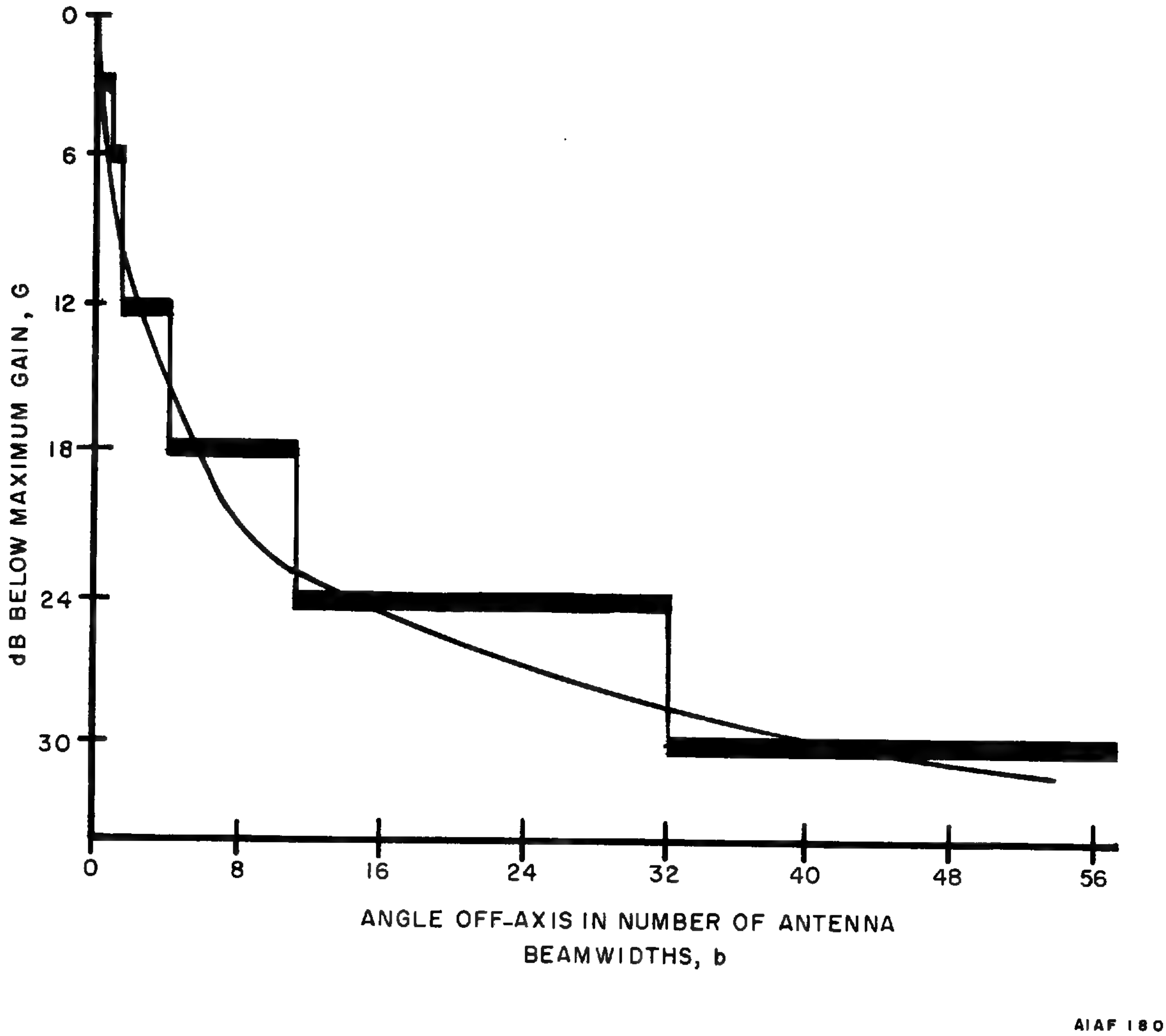

Figure 6-21. Envelope and Quantization of Cosecant Squared Antenna Pattern

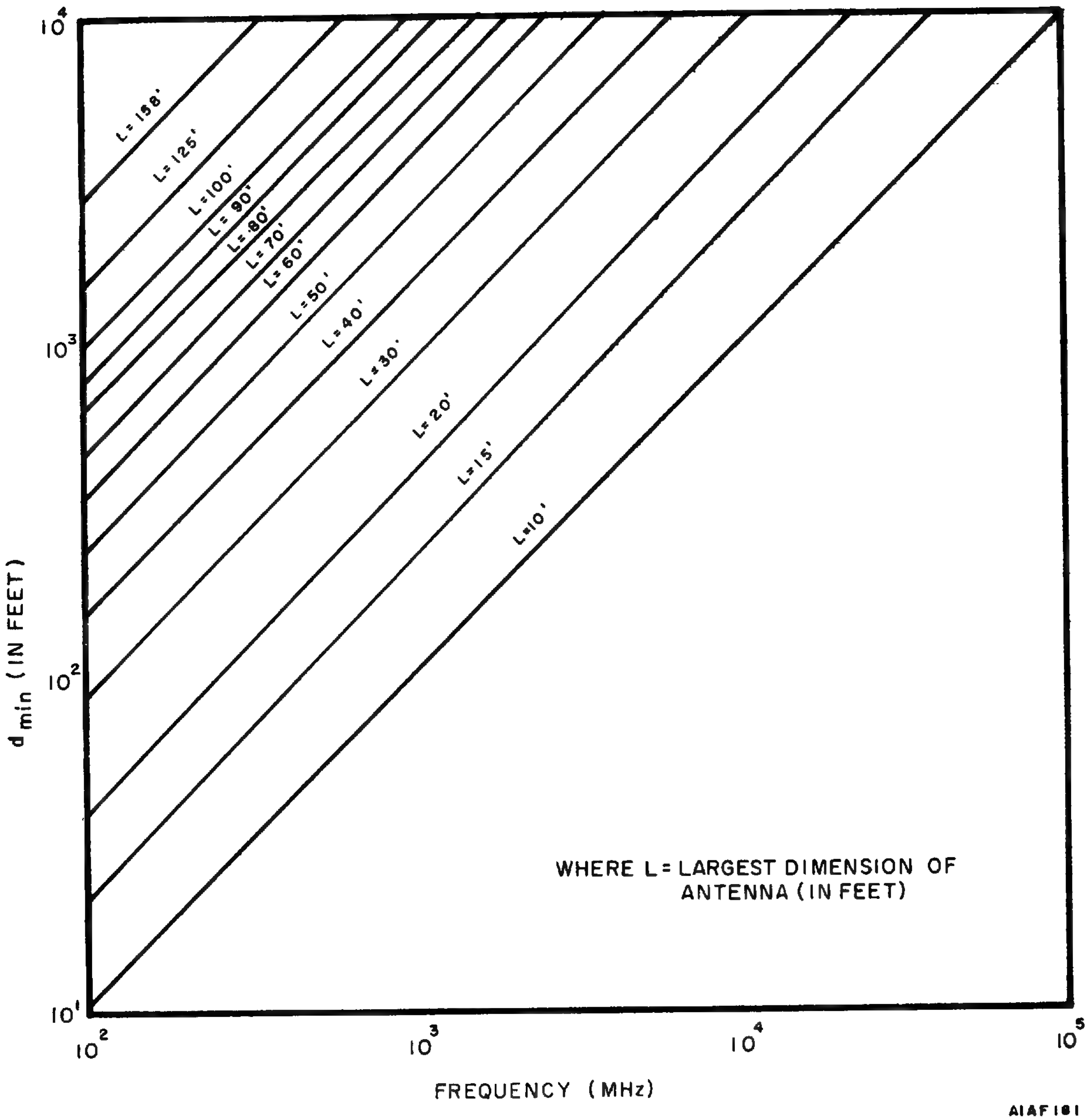

Figure 6 - 22. Minimum Distance Required for Fresnel Region Correction

where:

L is the largest dimension (diagonal) of the antenna in ft. and = $\sqrt{h^2 + v^2}$

h = horizontal dimension of antenna aperture in ft.

v = vertical dimension of antenna aperture in ft.

f = operating frequency in MHz

If the actual TX-RX separation is greater than the value obtained from equation (6-11) or figure 6-22, then no correction is required. If, however, the TX-RX separation is less than the Fresnel Region boundary, a correction must be applied for either the transmitter, receiver, or both antenna gains. The first step in the evaluation of the correction factor (C_{FR}) is to compute values of x and y in the following equation.

$$x = \frac{h_{(ft)} \sqrt{f_{MHz}}}{44.4 \sqrt{d_{ft}}} \tag{6-12}$$

$$y = \frac{v_{(ft)} \sqrt{f_{MHz}}}{44.4 \sqrt{d_{ft}}} \tag{6-13}$$

where:

d = distance between TX-RX (in feet)

After values of x and y are obtained, correction factors C_x and C_y are then determined from figure 6-23 if the antenna illumination is known. Unfortunately, the aperture illumination is unknown for many antennas, however, an estimate of the aperture illumination can be made by computing R in equation (6-14) or equation (6-15) and using this value with table 6-7.

Table 6-7. Estimate of Illumination

VALUE OF R	ESTIMATED ILLUMINATION
$0.88 \leqslant R < 1.2$	Uniform
$1.2 \leqslant R < 1.45$	Cosine
$1.45 \leqslant R < 1.66$	Cosine^2
$1.66 \leqslant R < 1.93$	Cosine^3
$1.93 \leqslant R < 2.03$	Cosine^4

$$R = \frac{\pi}{180} \; \frac{\Theta_H H}{\lambda} \tag{6-14}$$

where:

Θ_H = horizontal antenna beamwidth at the half power point (in degrees)

λ = wavelength (feet)

H = antenna horizontal dimension (feet)

or

$$R = \frac{\pi}{180} \; \frac{\Theta_V V}{\lambda} \tag{6-15}$$

where:

Θ_V = vertical antenna beamwidth at the half power points (in degrees)

V = antenna vertical dimension (feet)

Using the estimated illumination and previously computed values of x or y, Figure 6-23 may now be used to obtain C_x or C_y. The Fresnel region correction factor (C_{FR}) is simply the sum C_x and C_y and is entered in line 1.3.2.

o LINE 1.4, SUBTOTAL LINE 1.1.1 THROUGH 1.3.2, COLUMN A
This entry is the sum of entries 1.1.1 through 1.3.2 existing in Column A

o LINE 1.5, SUBTOTAL LINE 1.1.1 THROUGH 1.3.2 COLUMN B
This entry is the sum of entries 1.1.1 through 1.3.2 existing in Column B

o LINE 1.6, TOTAL LINE 1.4 - LINE 1.5 - EFFECTIVE RADIATED POWER (ERP)
This entry represents the effective radiated power of the TX (in dBm) and is obtained by subtracting the absolute value of line 1.5 from line 1.4. If possible, the quantity should be measured at the TX and inserted in Line 1.6.

6.5.2 Propagation

The space surrounding a transmitting antenna may be divided into several regions whose boundaries cannot be clearly defined. The Fresnel region lies adjacent to the antenna and extends to a distance of $2L^2/\lambda$ where L is the largest linear dimension of the antenna (or the diameter, D, for a round antenna) and is measured in the same units as λ.

The far field begins at the boundary of the Fresnel region. The first field to be encountered is the reflection field, so named because part of the energy existing at a receiver in this region is reflected from the earth. The geometry is shown in figure 6-24. This field extends to a distance equal to the sum of the transmitting antenna radio horizon and receiving antenna radio horizon, i.e., to a distance d, in miles given by:

$$d \approx \sqrt{2h_1} + \sqrt{2h_2} \tag{6-16}$$

where:

h_1 and h_2 are measured in feet.

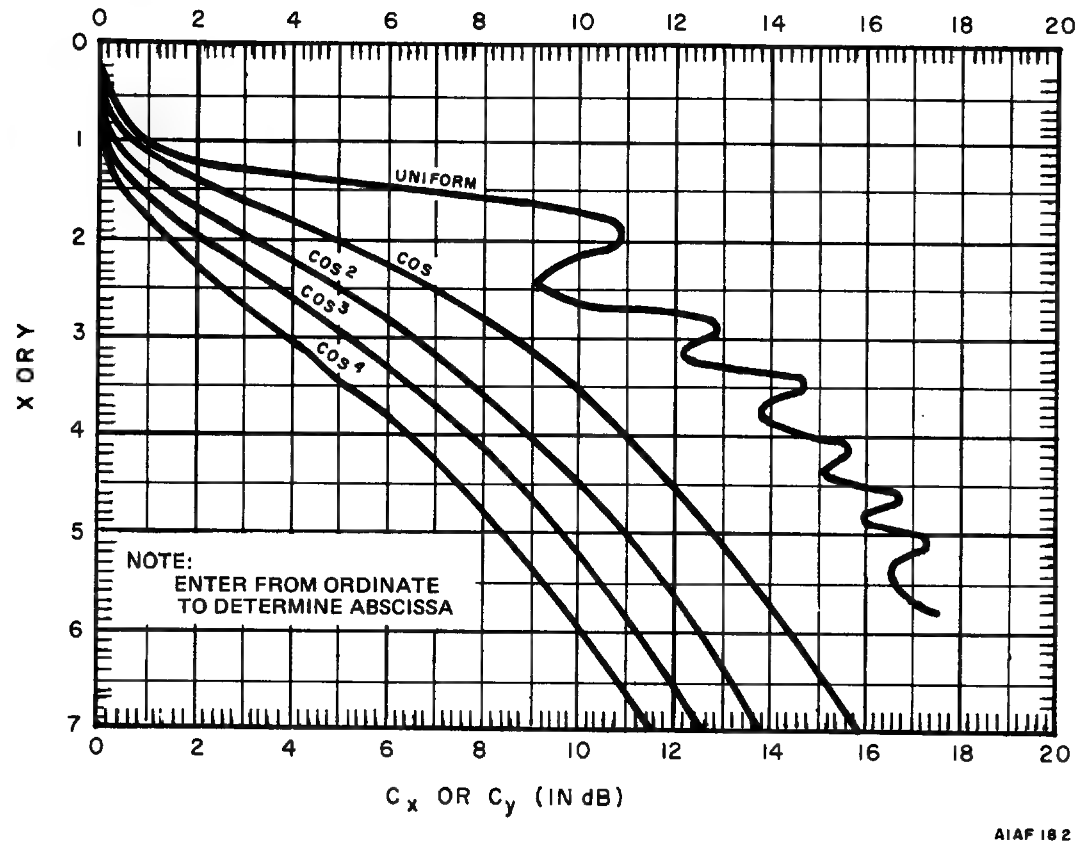

Figure 6 - 23. Fresnel Region Antenna Gain Correction Curves for Various Illuminations

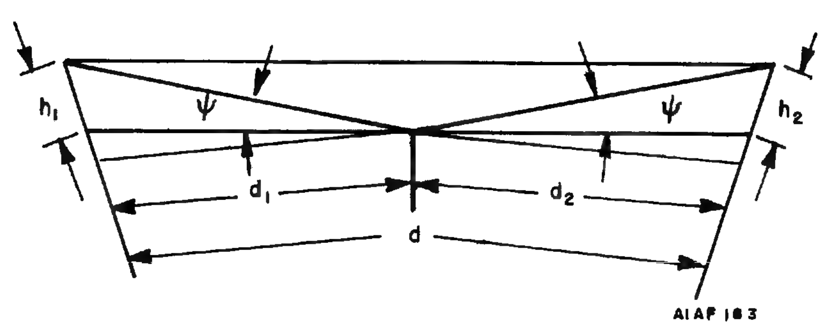

Figure 6 - 24. Geometry of Reflection Field (Line-of-Sight Propagation)

In the region immediately beyond the boundary of the reflection region the propagation effects change, but in view of the small area of a shore station it is very doubtful that any of the transmitter-receiver paths will extend beyond the reflection field. In the few cases where they do, the calculations for the reflection region will give a good approximation provided the range is not more than 5 or 10 percent greater than that calculated in the above equation.

o LINE 2.1, CONSTANT
This is a dimensional constant which must be included when totaling the entries of Section 2, Propagation.

o LINE 2.2, WAVE SPREADING TX-RX DISTANCE: - 20 log R_{mi}
The basic prediction equation includes the well known free space loss calculation between two isotropic gain antennas. The expression for this calculation is generally given in handbooks in the following form:

$$L_{fs} = 37\text{ dB} + 20 \log d_{mi} + 20 \log f_{MHz} \tag{6-17}$$

where:

L_{fs} = the free space loss in decibels.

f_{MHz} = the transmitted frequency in megahertz.

d_{mi} = the transmitter-receiver separation distance in statute miles.

o Entry 2.2 WAVE SPREADING - 20 log R_{mi} is equivalent to the 20 log d_{mi} expression in the above equation. The expression, 20 log f_{MHz} in the above equation is included in the ENTRY 3.2.2, RX FREQUENCY -20 log f_{MHz}, of the EMI PREDICTION CALCULATION form. The 37 dB constant is distributed between ENTRY 2.1 and the ENTRY 3.2.1 constant.

To perform a prediction using free space propagation losses, it is only necessary to enter figure 6-25 at the distance corresponding to the transmitter-receiver separation and read the numerical value on the ordinate, which is the value in dB corresponding to 20 log R_{mi}. This value is then entered in the prediction calculation form (in ENTRY 2.2). If only the effects of free space loss were to be considered, then ENTRIES 2.1 and 2.2 would be subtotaled in ENTRIES 2.6 and 2.7 and then totaled in ENTRY 2.8. The value of ENTRY 2.8 represents the propagation loss for the initial conditions specified at the top of the prediction form. When the value in ENTRY 2.8 is added to the value in ENTRY 1.6 (as is indicated in ENTRY 2.9), the total represents the power density existing at the RX antenna in dBm/m^2/MHz.

It can be seen from the foregoing discussion, and the development of the prediction equations given earlier that a complete prediction can be made using only entries 2.1, 2.2, 2.6, 2.7, 2.8 and 2.9, of the EMI PREDICTION FORM. However, this free space loss more often represents a minimum loss value and, consequently, higher interference levels will be predicted than will actually exist. Therefore, it is necessary to consider the additional effects which are associated with reflected, diffracted, and scatter modes of propagation. The more detailed analyses are especially important when a marginal case of interference is predicted using the free space loss effects only.

o LINE 2.3, REFLECTION FIELD
Whenever an electromagnetic wave is propagated through space and strikes a reflecting surface, such as the surface of the earth, it is changed in both magnitude and phase. The form to be used for performing reflection field propagation calculations is shown on figure 6-26.

The reflection field propagation loss calculations are a function of the transmitter/receiver: antenna height; polarization; separation; and reflecting surfaces coefficient of reflection. Each of these parameters are functions of the other variables shown in figure 6-26. The value to be calculated and entered in the EMI prediction form is the reflection field propagation loss in excess of free space losses (i.e., propagation losses entry 2.1) will always

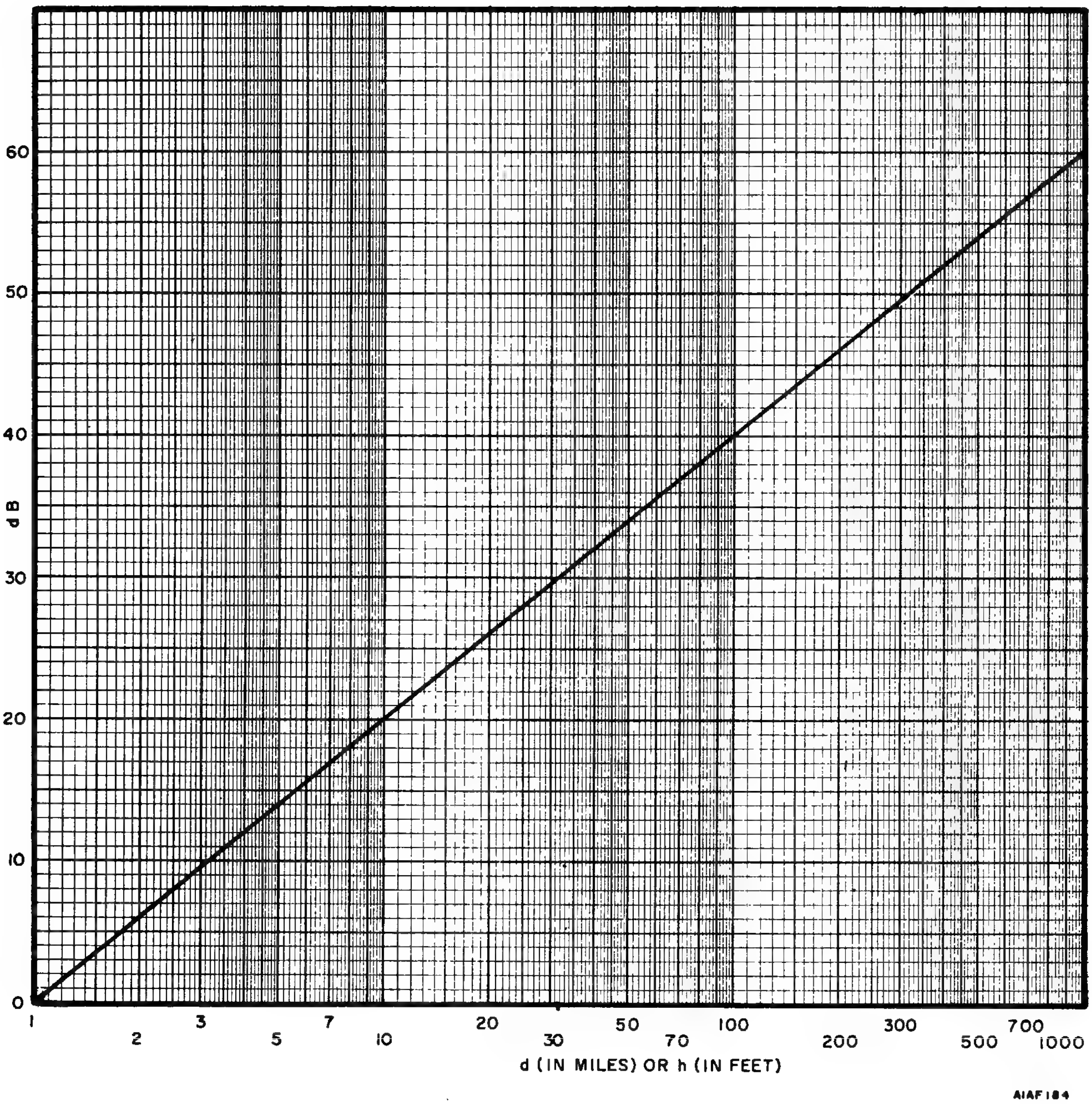

Figure 6 - 25. Convenience Factor 20 Log N

Transmitter (TX) ______ Receiver (RX) ______

Transmitter Site ______ Receiver Site ______

TX Antenna Height (h) ______ RX Antenna Height (h) ______ ft.

TX Antenna Polarization ______ Separation Between TX & RX (d) ______ mi.

Frequency of Interference ______ MHz σ = ______ ϵ = ______

1. CALCULATION OF DIVERGENCE FACTOR D

1.1 Calculate Distance to Reflecting Fresnel Area d_1 (c, m, b)

Step	Result
1.1.1 Calculate $c = \dfrac{h_1 - h_2}{h_1 + h_2}$	c =
1.1.2 Calculate $m = \dfrac{d^2 mi}{4(h_1 + h_2)}$	m =
1.1.3 Obtain "b" from Figure 6-27 (Use values of lines 1.1.1 and 1.1.2)	b =
1.1.4 Calculate $d_1 = \frac{d}{2}$ (1+b) (Use line 1.1.3)	d_1 =
1.1.5 Calculate $d_2 = d - d_1$ (Use line 1.1.4)	d_2 =

1.2 Determine Tangent of Grazing Angle ψ (tan ψ)

Step	Result
1.2.1 Enter h_1 in Figure 6-28	
1.2.2 Enter d_1 (from line 1.1.4) in Figure 6-28	
1.2.3 Read tan ψ from Figure 6-28	tan ψ =
1.3 Determine $\delta = d_1 d_2 / d$ (Use lines 1.1.4, 1.1.5, and d in Figure 6-29)	δ =
1.4 Divergence Factor D from Figure 6-30 (Use value of lines 1.2.3 and 1.3)	D =

2. CALCULATION OF REFLECTION COEFFICIENT

2.1 Vertical Polarization Reflection Coefficient

Step	Result
2.1.1 Calculate x term of $\bar{n}^2 = \epsilon_r - jx$ where $x = 18000\ \sigma / f_{MHz}$	x =
2.1.2 Obtain R_{90} Figure 6-31 (Use line 2.1. 1)	R_{90} =
2.1.3 Obtain Sin ψ_{90} Figure 6-31 (Use line 2.1.1)	Sin ψ_{90} =
2.1.4 Calculate $\rho = \dfrac{\text{Sin } \psi}{\text{Sin } \psi_{90}}$	ρ =
2.1.5 Obtain R Figure 6-32 (Use line 2.1.4)	R =
2.1.6 Obtain φ Figure 6-33 (Use line 2.1.4)	φ =

3. CALCULATION OF REFLECTED FIELD LOSS

Step	Result
3.1 Calculate (D) (R) product (lines 1.4 and 2.1.5)	DR =
3.2 Calculate Path Length Difference θ	
3.2.1 Using the data from Lines 1.2.3 and 1.3 and A. in Figure FO-1 read θ / f_{MHz}	θ / f_{MHz} =
3.2.2 Calculate $\theta = \theta / f_{MHz}\ (f_{MHz})$	θ =
3.3 Calculate ($\theta - \varphi$) total phase difference between reflected and direct difference (line 3.2.2 and line 2.1.6)	$\theta - \varphi$ =
3.4 Obtain g(θ) from B. in Figure FO-1 (Use lines 3.1 and 3.3)	g(θ) =
3.5 Calculate Loss "A" in excess of Free Space Loss -20 log g(θ) + 2.15 dB	A =

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Figure 6 - 26. Reflection Field Propagation Loss Calculation

be calculated. Losses calculated due to other propagation modes will include only those losses in excess of free space loss.

The first step to determine the reflected field strength at a point in space requires the solution of the reflection geometry involved. The geometrical considerations are shown in figure 6-24. The transmitter height, h_1, receiver location height, h_2, both above smooth earth, and great circle distance between the two locations are specified or obtained from a map or similar source.

The second step in determining the reflection field losses is the calculation of the reflection coefficient of the reflecting surface. The reflection coefficient $\bar{R}$ provides a measure of the change of magnitude and phase of a reflected electromagnetic wave. The reflection coefficient $\bar{R}$ is a function of the carrier frequency f_{MHz}, the relative permitivity of the reflecting surface $[\epsilon_r]$, the conductivity of the reflecting surface (σ), the grazing angle of incident ray on the reflecting surface (ψ) and polarization of carrier signal (h or v). The parametric relationships can be seen in the following equations:

$$\bar{R}_v = \frac{\bar{n}^2 \sin\psi - (\bar{n}^2 - \cos^2\psi)^{1/2}}{\bar{n}^2 \sin\psi + (\bar{n}^2 - \cos^2\psi)^{1/2}} \tag{6-18}$$

where:

$\bar{R}_v$ = Reflection coefficient for vertically polarized signal.

$$\bar{n}^2 = \epsilon_r - j\,18000\sigma/f_{MHz} \tag{6-19}$$

$$\bar{R}_h = \frac{\sin\psi - (\bar{n}^2 - \cos^2\psi)^{1/2}}{\sin\psi + (\bar{n}^2 - \cos^2\psi)^{1/2}} \tag{6-20}$$

where:

$\bar{R}_h$ = Reflection coefficient for horizontally polarized signal.

The third step is to combine the effects of steps 1 and 2 to obtain a value which represents a loss in excess of free space losses due to reflection field propagation. The following illustrative example is presented to demonstrate the application of the reflection field computation technique and associated figures. Assume the following conditions exist:

- o TX antenna height - 580 feet
- o RX antenna height - 30 feet
- o TX antenna polarization - Vertical
- o TX-RX separation - 25 miles
- o Frequency of interference - 6000 MHz

The above data is entered at the top of the Reflection Field Propagation Loss Calculation shown in figure 6-26. Section 1 of this figure encompasses the calculation of the divergence factor D. The divergence factor is a function of the transmitter/receiver geometry shown in figure 6-24.

Section 1.1 is used to calculate the distance d_1 (ref. figure 6-24) to the reflecting Fresnel Area. The determination of the distance d_1 is made using the following relationships.

$$d_1 = \frac{d}{2}(1 + b) \quad \text{where } b = \frac{d_1 - d_2}{d_1 + d_2} \tag{6-21}$$

$$h_1 = \frac{h_1 + h_2}{2}(1 + c) \quad \text{where } c = \frac{h_1 - h_2}{h_1 + h_2} \tag{6-22}$$

$$c = b + \frac{bd^2 (1 - b^2)}{4(h_1 + h_2)} \quad \text{for } K = 4/3 \tag{6-23}$$

$$c = bm(1 - b^2) \quad \text{where } m = \frac{d^2}{4(h_1 + h_2)\,\text{ft}} \tag{6-24}$$

Lines 1.1.1 and 1.1.2 are straightforward arithmetic computations to be performed as indicated.

- o Line 1.1.1 $c = \dfrac{h_1 - h_2}{h_1 + h_2} = \dfrac{580 - 30}{580 + 30}$

- o Line 1.1.2 $m = \dfrac{d^2_{mi}}{4(h_1 + h_2)} = \dfrac{(25)^2}{4(580 + 30)} = 0.256$

Using the values obtained from lines 1.1.1 and 1.1.2, and figure 6-27 determine the value of b and record this in line 1.1.3. Using the value of "b" perform the arithmetic operations indicated in lines 1.1.4 and 1.1.5 to obtain "d_1."

The tangent of the grazing angle (ψ) is obtained in line 1.2.3 using the values of h_1 and d_1 in figure 6-28.

Line 1.3 is solved, using figure 6-29 and the values of d_1, and d_2 and "d" previously specified or calculated.

Line 1.4 is solved using the values of 1.2.3 and 1.3 in figure 6-30.

o LINE 2.1, VERTICAL POLARIZATION

Determine R_{90} (Line 2.1.2) and sin ψ_{90} (Line 2.1.3) from figure 6-31 corresponding to the values of σ and ϵ_r obtained from Table 6-8.

Calculate $\rho = \dfrac{\sin \psi}{\sin \psi_{90}}$ (Line 2.1.4) where ψ is the grazing angle under consideration.

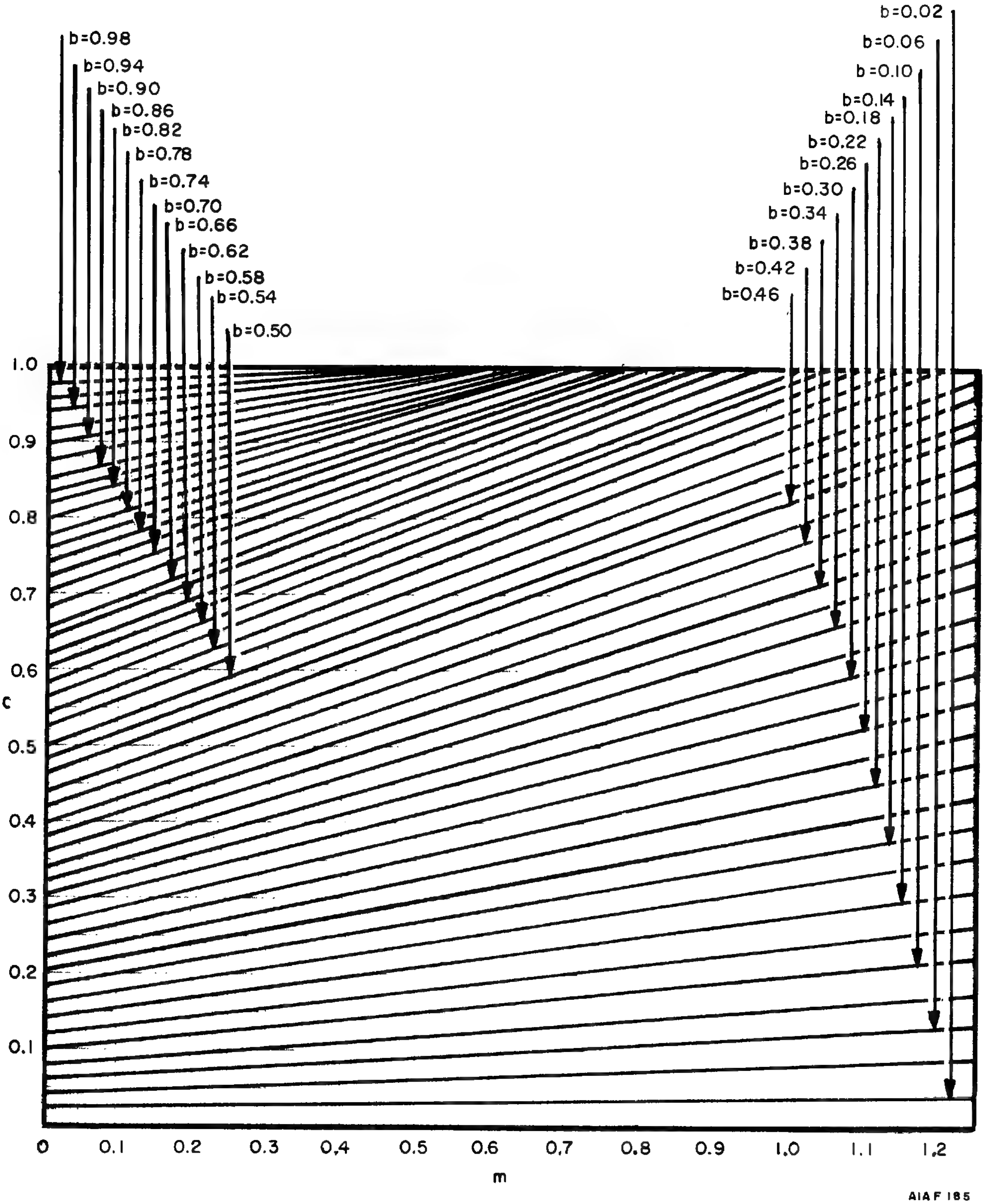

Figure 6 - 27. Nomogram for Determining b From Cubic Equation (6-24)

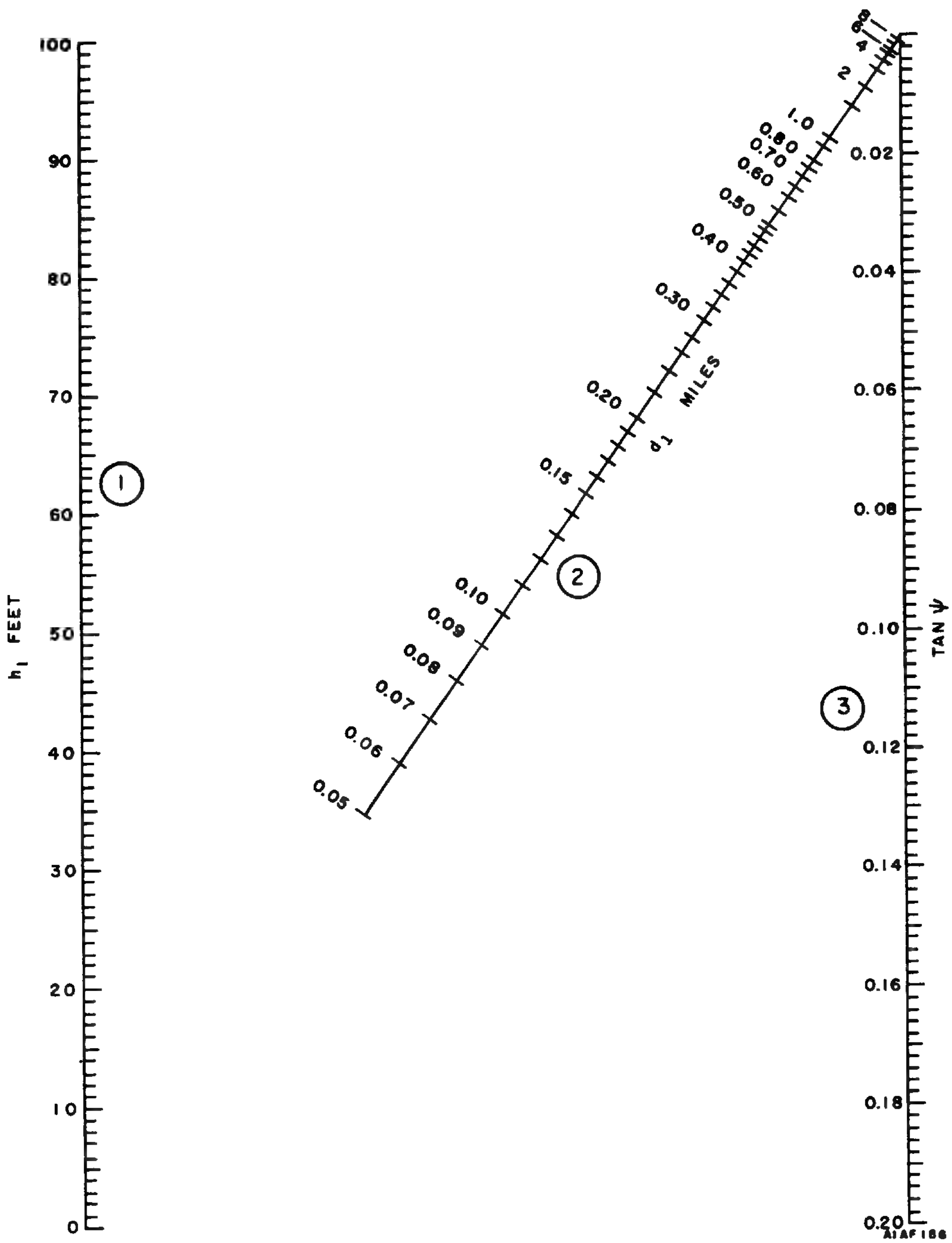

Figure 6 - 28. Nomogram for Determining Tan ψ

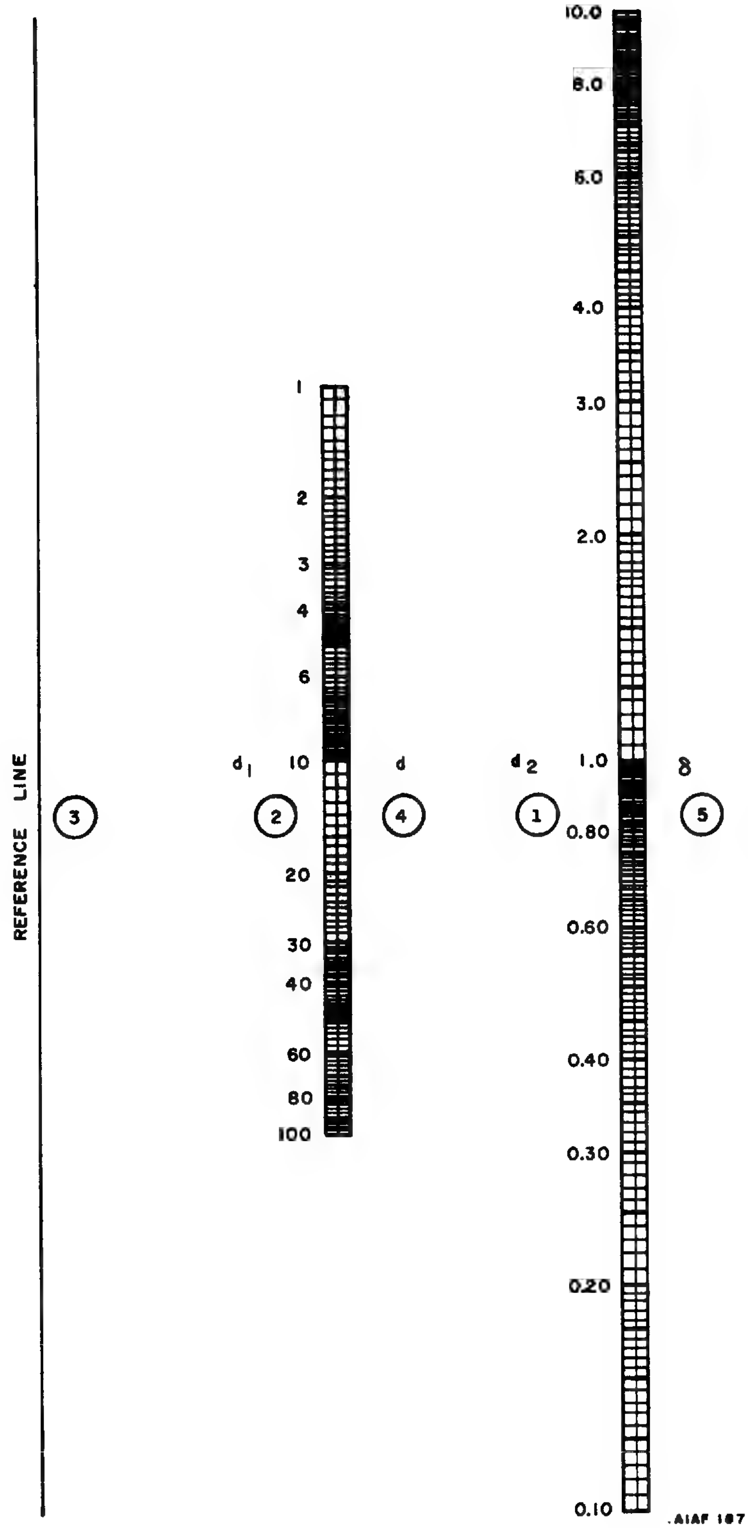

Figure 6 - 29. Nomogram for Determining δ

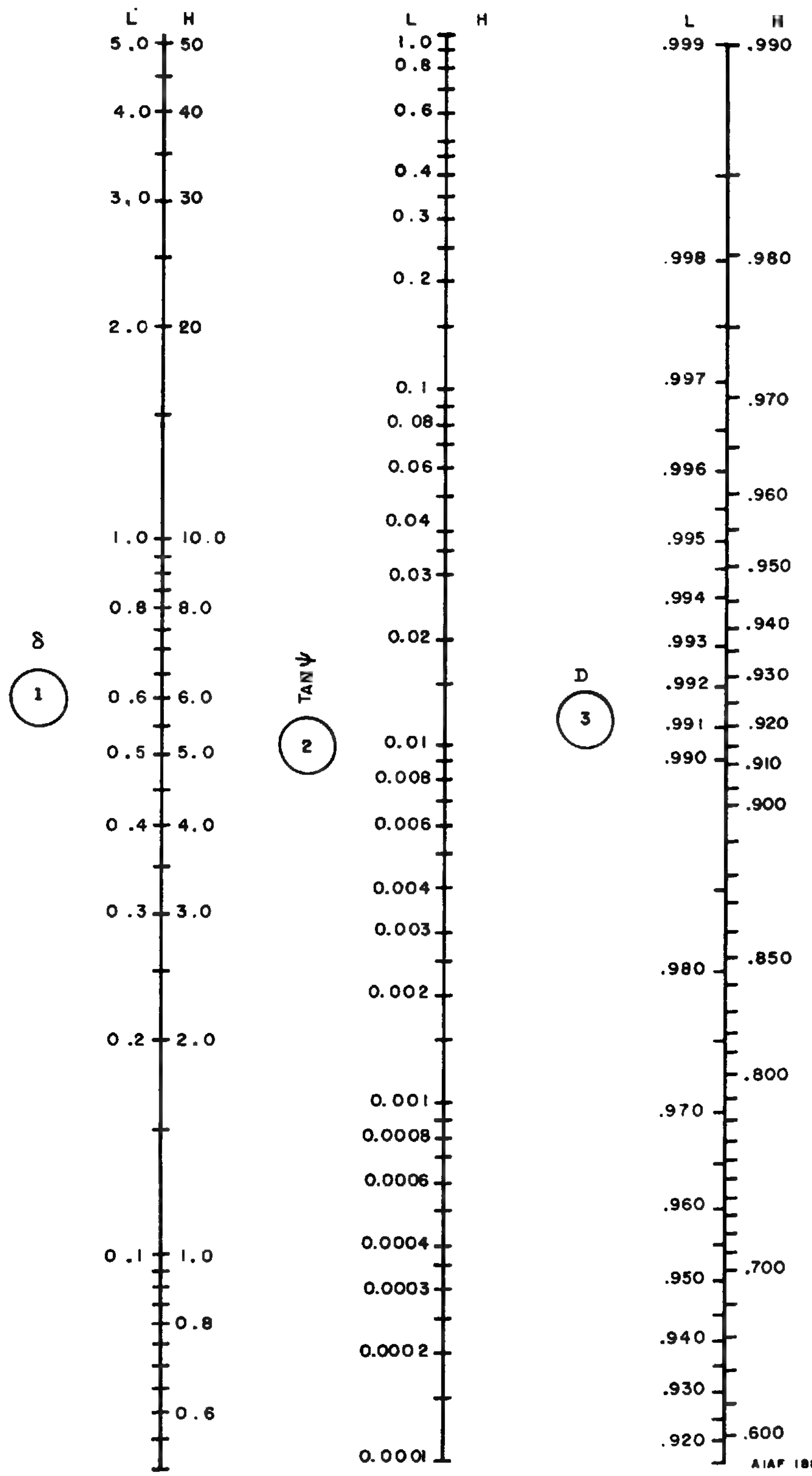

Figure 6 - 30. Nomogram for Determining D When K = 4/3

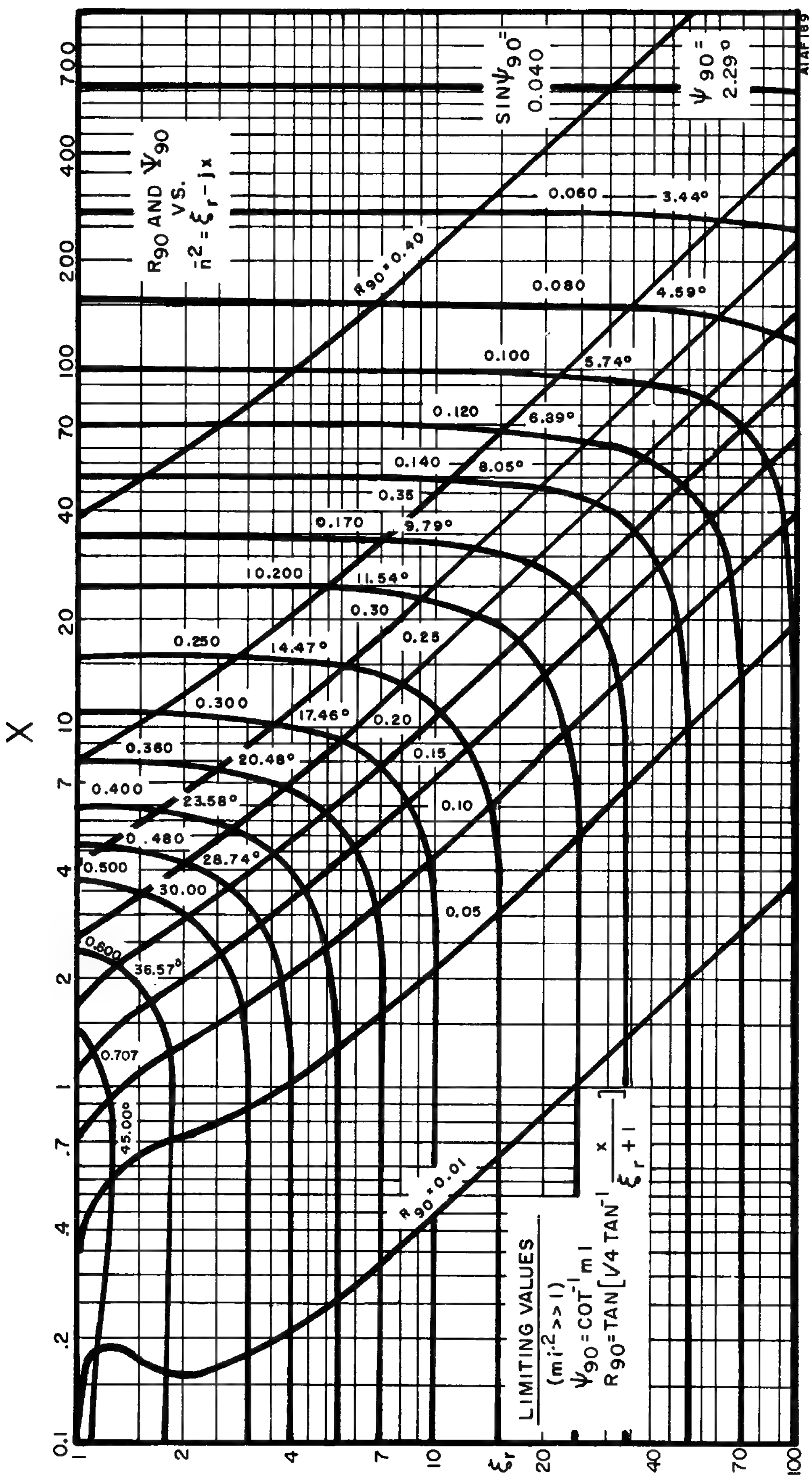

Figure 6 - 31. Limiting Values

Table 6-8. Representative Values of Permitivity and Conductivity for Various Reflecting Surfaces

TYPE OF SURFACE	PERMITIVITY ϵ_r	CONDUCTIVITY σ mho-m/m^2
Sea water	81	4.64 to 5.0
Fresh water	81	0.005
Tundra	5	0.0004
Glacial ice	3	0.000025
Arctic ice	3	0.0001 to 0.010
Marsh land	30	0.111
Average land	15	0.0278
Desert land	3	0.0111

From figure 6-32 corresponding to R and the calculated value of ρ determine the magnitude of the reflection coefficient. From figure 6-33 determine the phase of the reflection coefficient.

6.5.3 Receiver

The effects of the receiver upon the static EMI situation may be described by the following equation:

$$\text{Receiver contribution} = \frac{K\, G_r\, B_r}{L_p\, L_r\, f^2\, N} \tag{6-25}$$

where:

K = the constant of proportionality

G_r = the receiver antenna gain

B_r = the receiver 3 dB bandwidth

L_p = the polarization mismatch loss

L_r = the receiver transmission line loss

f = the receiver frequency

N = the receiver internal noise power

The receiver portion of the prediction sheet presents the receiver parameters given above and the modifications for each of these contribution requisite to making a prediction (refer to figure 6-1).

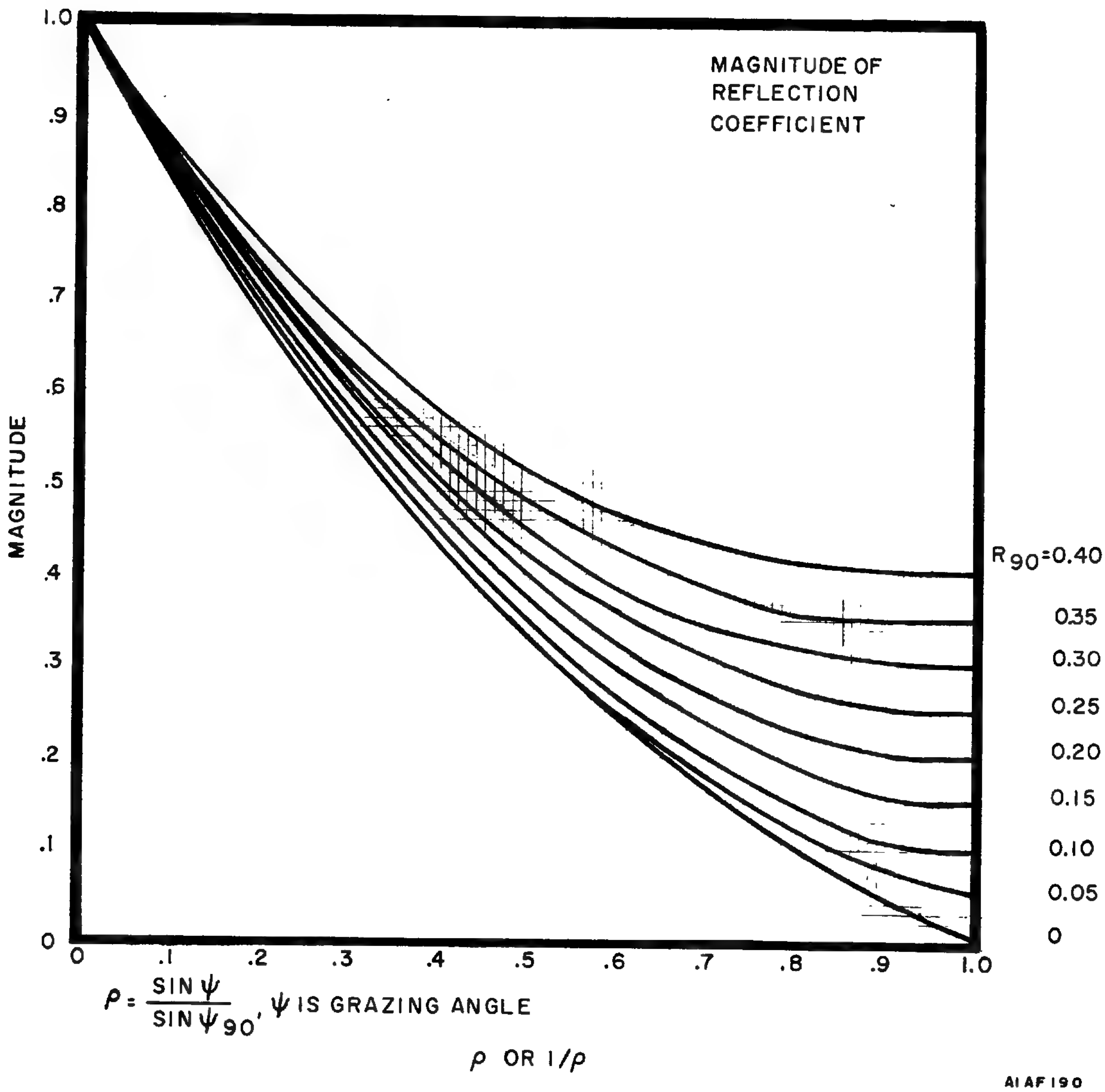

Figure 6 - 32. Magnitude of Reflection Coefficient

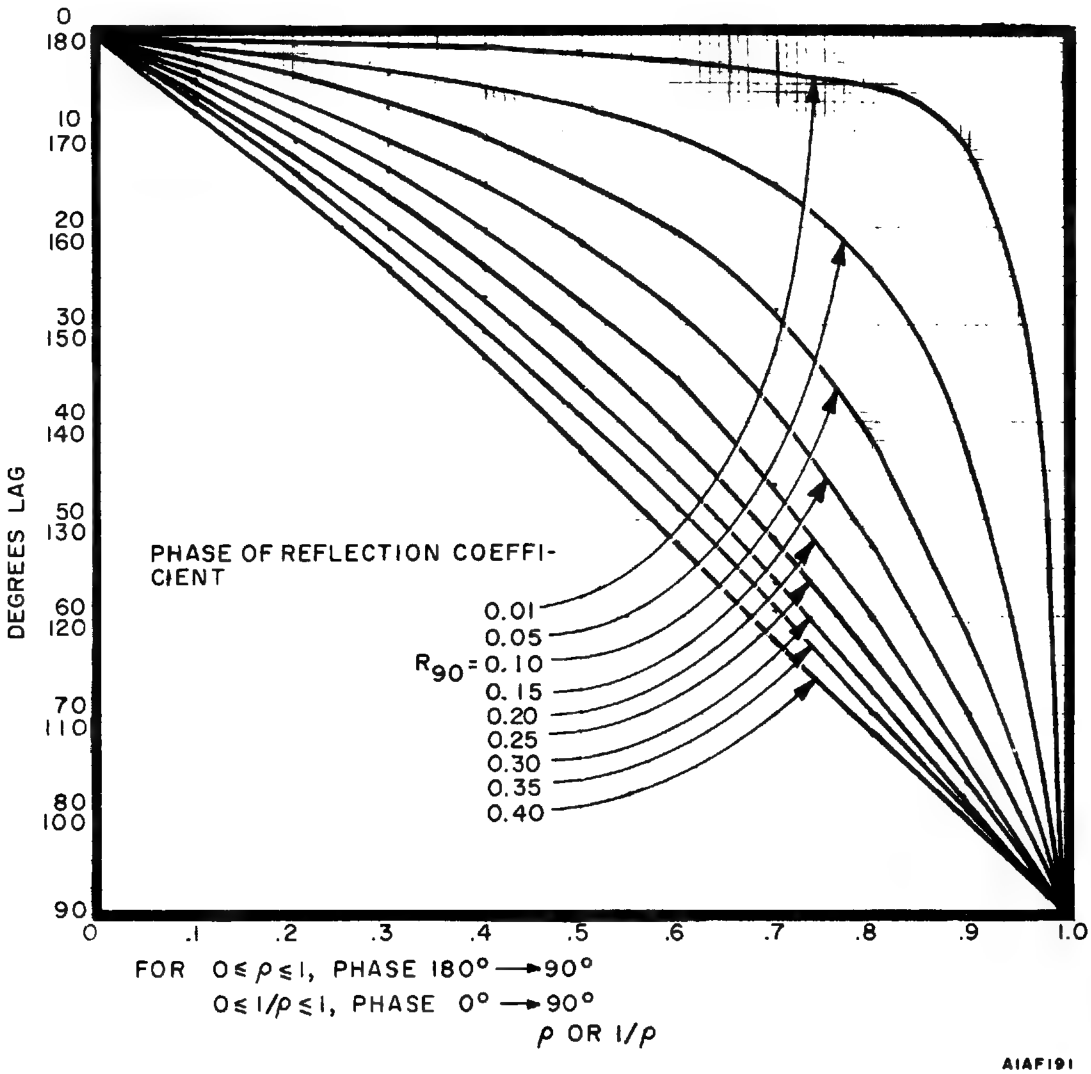

Figure 6 - 33. Phase of Reflection Coefficient

o EXPLANATION OF ENTRIES IN RECEIVER SECTION OF THE CALCULATION SHEET

This section discusses how each of the variables may be calculated or estimated to describe the dynamic situation for the principal types of receivers considered in this report, i.e., radar receivers, communications receivers, and microwave relay receivers.

o LINE 3.1, LOSS DUE TO POLARIZATION MISMATCH: P_{dB}

This entry is the measured loss due to the difference in polarization between an arriving wave and the receiver antenna. If this loss is not known, it can be approximated by the use of Table 6-9. This table is based on a statistical compilation of measurements on the polarization loss in radar antennas.

Table 6-9. Transmitter - Receiver Polarization Alignment Factors (Expressed In Units Of dB Loss)

		ARRIVING OR TRANSMITTER POLARIZATION					
		Horizontal L_p	Vertical L_p	Diagonal L_p	Elliptical L_p	Circular RH L_p	Circular LH L_p
RECEIVER POLARIZATION	Horizontal	0	20	3	3	3	3
	Vertical	20	0	3	3	3	3
	Diagonal	3	3	0	3	3	3
	Elliptical	3	3	3	0	5	5
	Circular RH	3	3	3	5	0	25
	Circular LH	3	3	3	5	25	0

o LINE 3.2, RX EFFECTIVE ANTENNA AREA: $10 \log A_r$

This entry pertains to the effective area of the receiver antenna. If this quantity is known, it should be entered in the equation in Line 3.2 in units of meters squared. If the effective area is less than 1 meter, this quantity will be negative and should be entered in Column "B" (-dB). If the area is greater than 1 square meter the quantity should be entered in Column "A" (+dB). If this quantity is not known, Lines 3.2.1 through 3.2.3 should be filled out.

o LINE 3.2.1, CONSTANT

This is a constant of portionality which converts the RX Effective Antenna area into the antenna gain in dB above isotropic and frequency in MHz. It is always + 38.6 dB and is entered in Column "A".

o LINE 3.2.2, RECEIVER RADIO FREQUENCY: $-20 \log f_{MHz}$

This term expressed in dB corresponds to the operational receiver radio frequency in MHz. For convenience, this term is plotted in figure 6-34.

o LINE 3.2.3, RX ANTENNA GAIN: G_r (dB)
The explanation for Line 1.3 applies equally well here.

o LINE 3.2.3.1, LOSS DUE TO OFF-AXIS POINTING AT TX:
The explanation for line 1.3.1 is the same as for line 3.2.3.1

o LINE 3.2.3.2, LOSS DUE TO NEAR FIELD EFFECT:
The explanation of the near field effect in Line 1.3.2 applies here also.

o LINE 3.3, RX TRANSMISSION LINE LOSS L (dB)
See discussion for line 1.2

o LINE 3.4, SUBTOTAL COLUMN A
This entry is the sum of entries 3.2, 3.2.1, 3.2.2 and 3.2.3 shown in Column A.

o LINE 3.5, SUBTOTAL COLUMN B
This entry is the sum of entries 3.1, 3.2, 3.2.2, 3.2.3.1, 3.2.3.2, and 3.3 shown in Column B.

o LINE 3.6, TOTAL
Line 3.6 represents the factor which translates the interference power present at the receiver antenna to that present at the receiver input terminals. This quantity is determined by subtracting the absolute value of Line 3.5 from Line 3.4.

o LINE 3.7, RECEIVED INTERFERENCE POWER (dBm)
This entry represents the interference power present at the receiver input terminals. It is obtained by adding algebraically Lines 2.9 and 3.6. The total of these two items is then entered in Column C or D, whichever is applicable.

o LINE 3.8, RX BANDWIDTH
The following entries consider the effect of the RX bandwidth on the interference power. Fundamental cochannel $BW_{RX} > 2/\tau$ is not included on the calculation sheet because the receiver will accept all of the transmitter power.

Figures 6-35 and 6-36 illustrate the bandwidths of certain AM and FM receivers which operate in various portions of the frequency spectrum. These entries are all calculated with respect to a megahertz, therefore, when the bandwidth is less then a megacycle the quantity goes in Column "B" (-dB). If the bandwidth is greater than a megahertz the value goes in Column "A".

o LINE 3.8.1, FUNDAMENTAL COCHANNEL INTERFERENCE WHERE $BW_{RX} < 2/\tau$ (RADAR TX)
This line represents the interference case for which the receiver 3 dB bandwidth is less than the theoretical transmitter 3 dB bandwidth. The amount of power entering the cochannelly located receiver becomes a function of both the transmit and receive bandwidths.

o LINE 3.8.1.1, log $0.5\tau BW_{RX}$
This equation determines the amount of power admitted by the bandwidth of the receiver discussed in Line 3.8.1.

o LINE 3.8.2, FUNDAMENTAL ADJACENT CHANNEL INTERFERENCE (RADAR TX)
This line represents the case of the above interference for which the receiver will accept an amount of transmitted power whose bandwidth is equal to the receiver's bandwidth.

o LINE 3.8.2.1, log (BW_{RX}) MHz
This equation determines the amount of power admitted by the bandwidth of the receiver as discussed in Line 3.8.2.

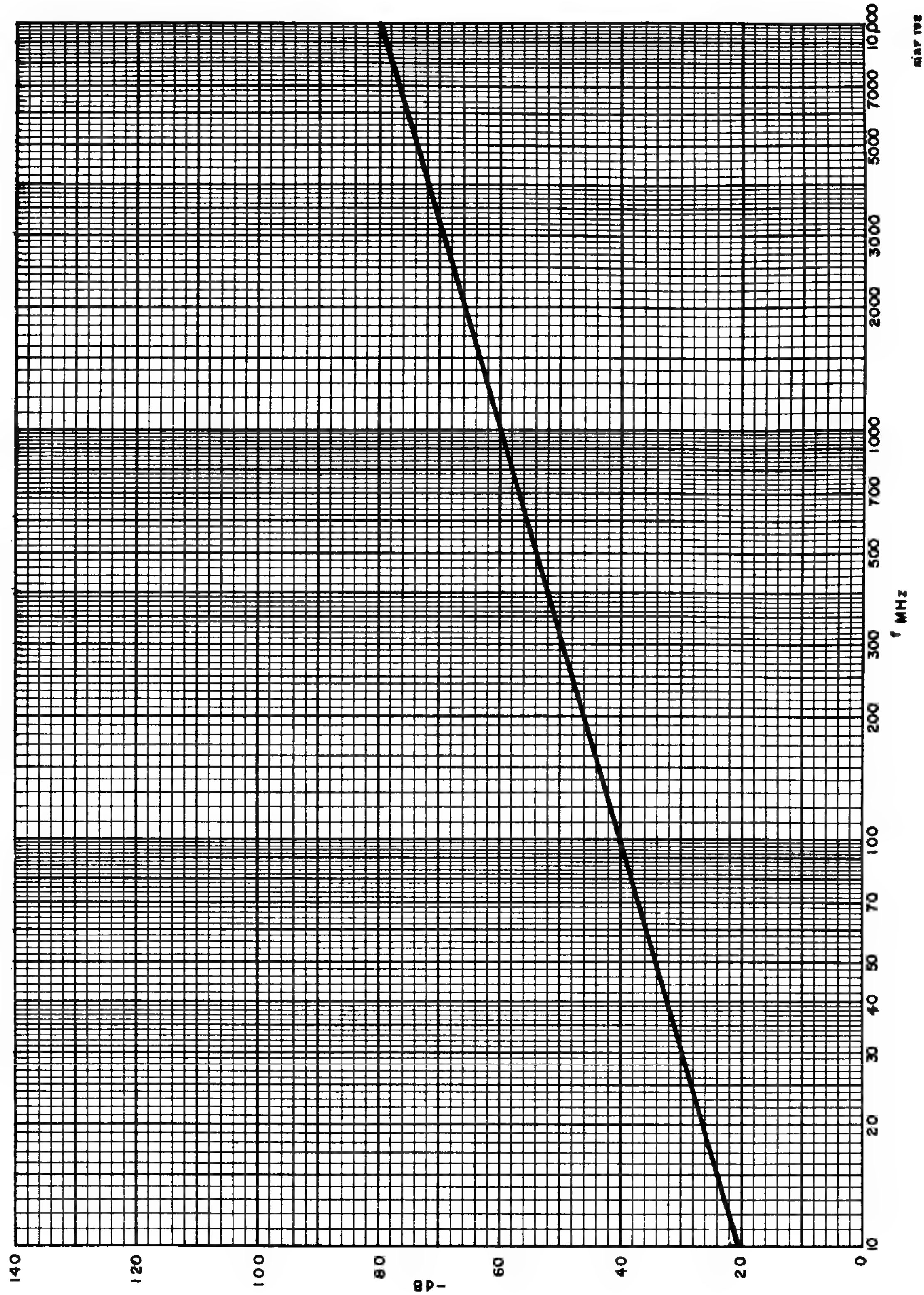

Figure 6 - 34. Graph of 20 Log f MHz

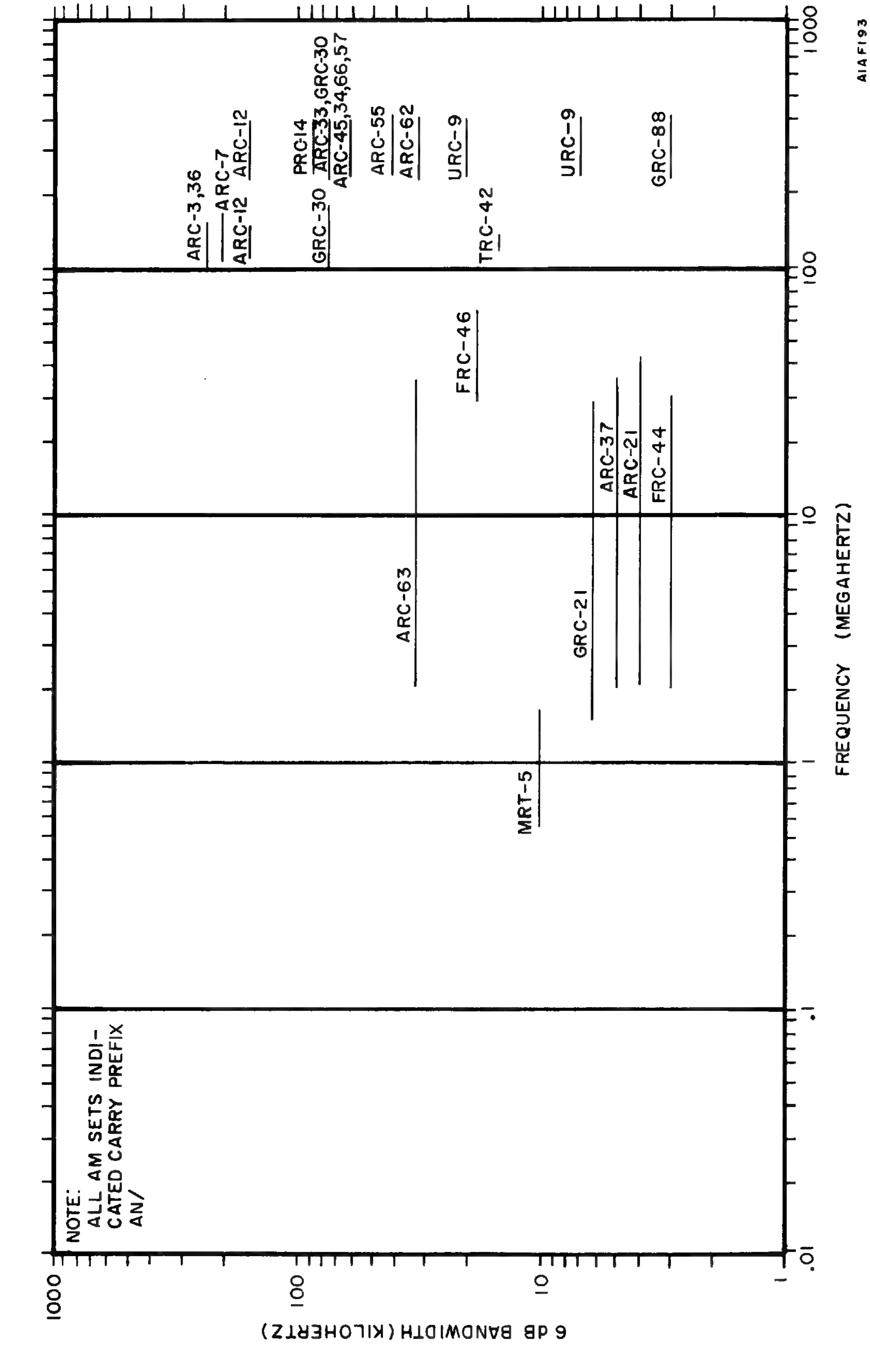

Figure 6 - 35. Bandwidth vs. Frequency, AM Sets

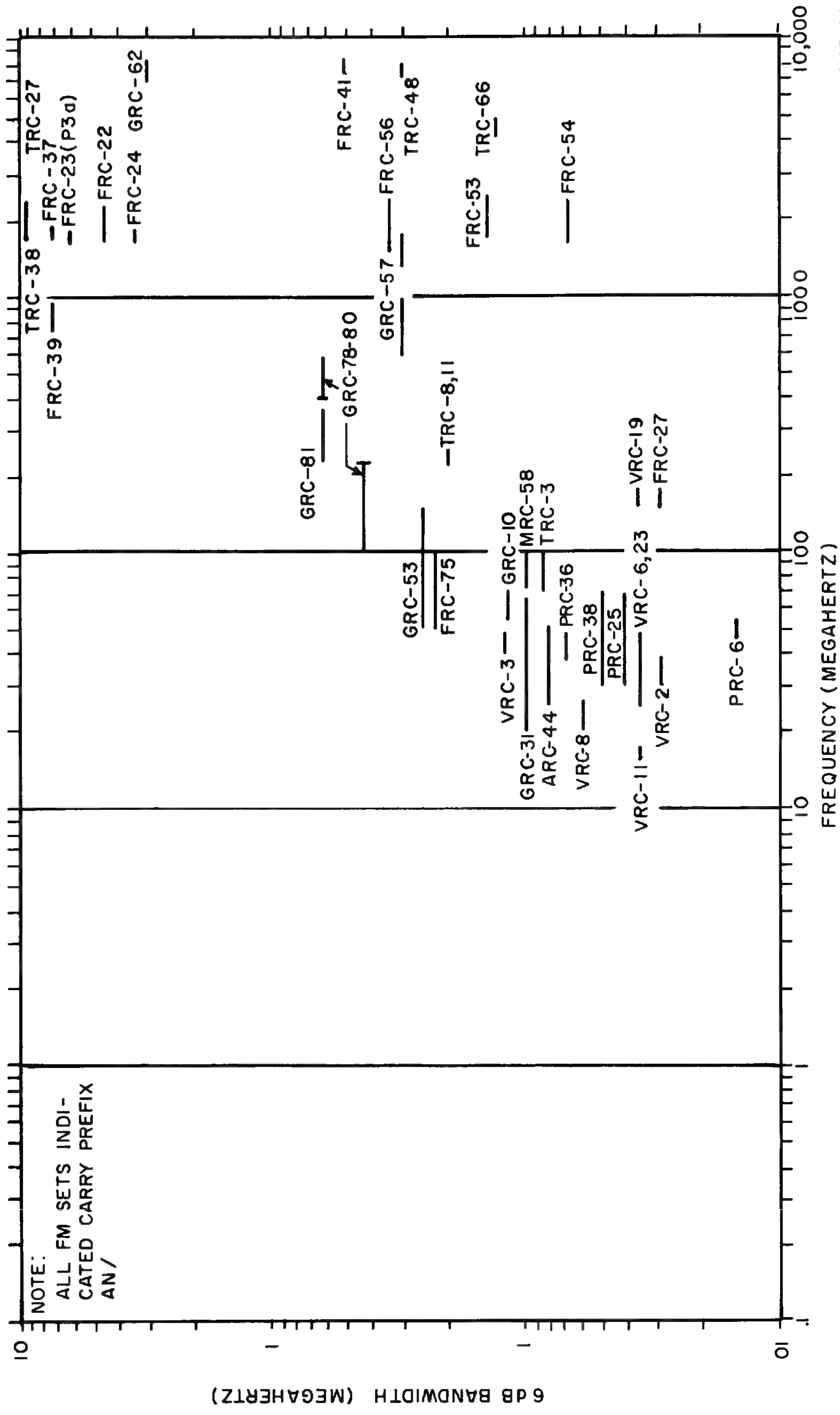

Figure 6 - 36. Bandwidth vs. Frequency, FM Sets

o LINE 3.8.3, HARMONIC COCHANNEL INTERFERENCE WHERE $BW_{RX} < 2/\tau$ (RADAR TX)

The discussion for Line 3.8.1 and Line 3.8.3 is that the transmitted power level be correctly adjusted and this was accounted for Line 1.1.3.

o LINE 3.8.4, HARMONIC ADJACENT CHANNEL INTERFERENCE WHERE $BW_{RX} < 2/\tau$ (RADAR TX)

The discussion presented in Line 3.8.2 is valid for this line also, since the only difference between the case of EMI for Line 3.8.2 and Line 3.8.4 is that the transmitted power level must be adjusted accordingly. This was done in Line 1.1.4.

o LINES 3.8.5 and 3.8.6, RX BANDWIDTH EFFECTS ON TRANSMITTED POWER BY COMMUNICATIONS TRANSMITTERS

These two lines represent the amount of transmitted power admitted to a receiver when the transmitter in question is a communications transmitter. Lines 3.8.5 and 3.8.6 evaluate the ratio of the receiver and the transmitter bandwidths.

o LINE 3.9, RX SENSITIVITY IN UNITS OF -dBm; N_{dBm}

This is the threshold receiver sensitivity (expressed in -dBm) and is normally available from the manufacturer's specifications. If necessary, it may be estimated by the use of figure 6-37 and the following equation:

$$N = (\text{sensitivity from figure 6-37}) + Z + 10 \log BW_{RX} \qquad \textbf{(6-26)}$$

Where:

$Z = 0$ for 100 percent AM

$Z = 5$ for FM of any deviation ratio

BW_{RX} = the receiver 3 dB bandwidth in kHz

The previous equation does not apply, however, to microwave relay receivers. A sensitivity of -55 dBm should be assumed for microwave relay receivers, unless design or measured data are available.

o LINE 3.10, SUBTOTAL, LINE 3.8 THROUGH 3.9 EXISTING IN COLUMN "A"

Line 3.10 is the sum of all entries from Line 3.5 through 3.9 in Column A.

o LINE 3.11, SUBTOTAL, LINE 3.8 THROUGH 3.9, COLUMN "B"

This entry is the sum of all entries in Column "B" from Line 3.8 through 3.2.

o LINE 3.12, TOTAL, LINE 3.10 - Line 3.11 = ADJUSTED RX THRESHOLD

By subtracting the absolute value of Line 3.11 from 3.10, a value is obtained for the receiver threshold which has been adjusted to the particular type of interference being received.

o LINE 4.1, I/N RATIO, TOTAL OF LINE 3.7 + LINE 3.12

This entry represents the interference power existing at the receiver input terminals referenced to the adjusted receiver threshold. The I/N ratio is obtained by algebraically adding the received interference power (Line 3.7), Column C or D, to the adjust RX threshold (Line 3.12), Column C or D.

o LINE 4.2, ASSUMED OR KNOWN $(S/N)_{dB}$ RATIO

To predict S/I, it is necessary to know the operational signal-to-internal-noise ratio of the potentially interfered receiver. This may be measured, calculated, or obtained from user or manufacturer's application data and is entered in Column C. The following discussion will assist in estimating the operational S/N ratio.

o RADAR OPERATIONAL S/N RATIOS

The classical radar equation can be used to calculate the ratio of received signal power to radar receiver noise when the radar is echo tracking.

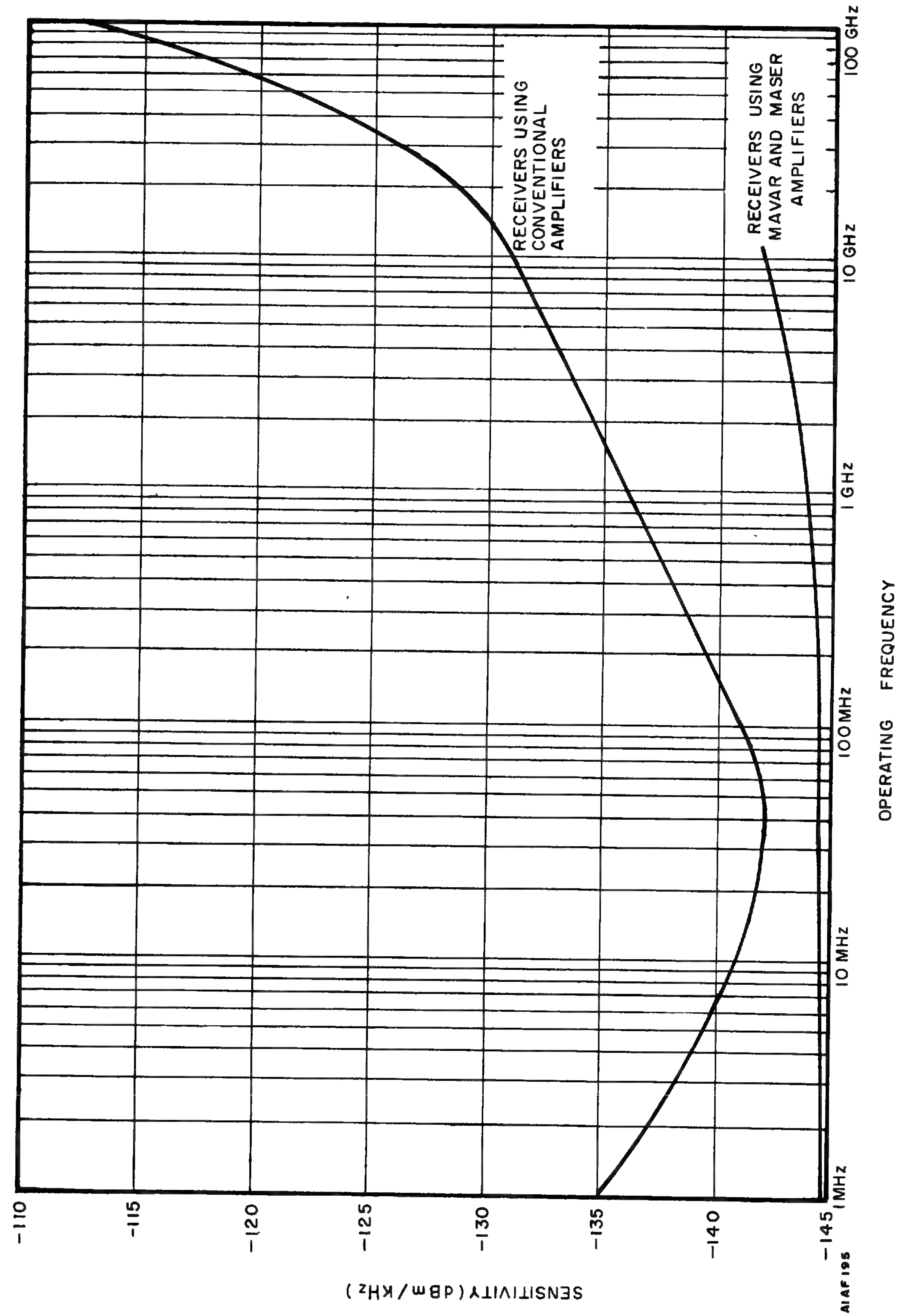

Figure 6-37. Typical Receiver Sensitivity (dBm)

$$S/N = 10 \log \frac{P_t G^2 \lambda^2 A}{(4\pi)^3 R^4 KTB\,NFL} \quad (dB) \qquad (6\text{-}27)$$

where:

P_t is the transmitted peak power in watts
G is the main lobe antenna gain (dimensionless)
λ is the wavelength (meters)
A is the cross section area of the target $(meters)^2$
R is the range to the target (meters)
K is Bolzmann's Constant = 1.38×10^{-23} joules/deg.
T is the temperature at the receiver in degrees Kelvin
B is the bandwidth in hertz
NF is the receiver noise figure (dimensionless)
L represents the various losses encountered in the entire system (dimensionless).
S/N is the IF signal-to-noise ratio during reception of the pulse.

Equation 6-27 represents the S/N ratio for any specific situation.

The operational signal-to-noise ratio of the FPS-16 is 16 (12 dB) and is typical for tracking radars in this class. The operational S/N ratio for most radars falls in the area of + 10 dB and this quantity may be used if no other estimates are available.

o COMMUNICATIONS OPERATIONAL S/N RATIOS

As in the case of radars, the operational S/N ratio can only be determined by the individual user. However, table 6-10 can be used to estimate S/N ratios for various types of communications systems.

o MICROWAVE RELAY RECEIVERS

The S/N ratio of microwave relay links is typically about 20 dB and is generally maintained through a 30 dB signal fade.

o LINE 4.3, FIGURE PREDICTED (S/I) RATIO

Since it is ultimately the S/I ratio that is used as an operational measure of the potential EMI due to radiations from transmitters, this ratio is determined by subtracting I/N ratio (Line 4.1) from the S/N ratio (Line 4.2).

Table 6-10. Signal - to - Noise Ratio

TYPE OF RADIO SERVICE	APPROXIMATE MINIMUM S/N (DECIBELS)
1. Double-sideband radiotelephony (3 kilohertz bandwidth)	20
2. Single-sideband radiotelephony (3-kilohertz bandwidth)	20
3. Broadcasting (5-kilohertz bandwidth)	20
4. Manual morse radiotelegraphy (for average operators)	0
5. Frequency-shift radiotelegraphy (60-word teleprinter speed)	10
6. Single-sideband two-tone radiotelegraphy, one tone marking and one tone spacing, 60-word speed	8
7. Single-sideband four-tone radiotelegraphy, two tones marking and two tones spacing, 60-word speed	6
8. Radio facsimile with 8-decibel contrast ratio using double-sideband amplitude modulation	18
9. Radio facsimile with 8-decibel contrast ratio using carrier-shift	12

o LINE 4.3.1, FOR I/N $>$ 0 dB; (S/I)dB = (S/N)dB LINE 4.2 - LINE 4.1
Should the I/N ratio be greater than zero (LINE 4.1 is positive) the calculation of S/I is made here. This quantity will be negative unless the I/N (Line 4.1) ratio has a value which lies between 0 dB and -(S/N) ratio, in which case Line 4.3.1 will have a small positive value.

o LINE 4.3.2, For I/N $\leqslant$ 0 dB; (S/I)dB = (S/N)dB NO INTERFERENCE EXISTS
Should the I/N be less than or equal to zero, (Line 4.1 is negative) the S/I ratio will be due to the inherent noise characteristics of the receiver alone and not due to the selected transmitter. Hence, EMI is said not to exist.

6.6 INTERPRETATION OF RESULTS

Once the S/I ratio existing at the subject receiver input has been determined (Line 4.3.1) it is necessary to translate these S/I ratios to the presentation device, which may be visual, voice or in terms of intelligibility content. These ratios can then be used as a basis for either making recommendations, or taking corrective action. A nominal criteria for the static scoring of the calculated S/I ratios is given in Table 6-11. In those situations where one or both of the antennas are scanning, it is necessary to modify the static criteria to include the time variant effects.

Table 6-11. Scores and Interpretations of S/I Ratios

SCORE	INTERPRETATION	DIGITAL DATA OR RADAR*	VOICE	TV AND FAX
A	Highly improbable	$S/I \geq 25$	$S/I \geq 10$	$S/I \geq 35$
B	Unlikely	$15 \leq S/I < 25$	$0 \leq S/I < 10$	$25 \leq S/I < 35$
C	Marginal	$5 \leq S/I < 15$	$-10 \leq S/I < 0$	$15 \leq S/I < 25$
D	Likely	$-5 \leq S/I < 5$	$-20 \leq S/I < 10$	$5 \leq S/I < 15$
E	Highly probable	$S/I \leq -5$	$S/I < -20$	$-5 \leq S/I < 5$

* Based on isotropic illumination.

6.6.1 Static Scoring Criteria

Nominal user value judgements versus the mean S/I are given in figure 6-38 for voice, digital data, radar return, television or fax. The nominal voice scores are based on studies of military field test data made by the U.S. Army Electronics Command (USAECOM) at Ft. Monmouth; the digital data scores are based on an averaging of many data links for the TD-2 microwave relay; and the TV scores are based on an averaging of the acceptability criteria developed by the Television Allocation Study Organization. A further statistical ordinate for scanning radars is presented on the right margin.

These values are subjective and wherever specific scoring, or decision criteria are available to those making predictions, these criteria should replace the nominal subjective judgements suggested in figure 6-38.

The process of EMI prediction has many uncertainties giving rise to the question of what confidence value to be placed on the results obtained. The user scores depicted in figure 6-38 have a probable variation (uncertainty) of $\pm A_\mu$ corresponding to an error interpreted to be "Good" when it should have been "Poor" or vice versa. The A_μ is smaller for digital data and larger for TV as evidenced in Table 6-11. The predicted S/I has an attendent uncertainty, A_ρ, due to the statistical combination of the variations in transmitter power, propagation loss, receiver properties, etc. The total probable variation, A, is the statistical sum of each variation.

$$A = \sqrt{A_\mu^2 + A_\rho^2} \tag{6-28}$$

The interpretation now to be put on A is that any score (good, poor, etc.) will likely be in error by $\pm$A. Empirically, A is believed to be at least as great as 5 dB when uncertainties due to many situations are averaged. Toward this end, Table 6-11 is obtained from figure 6-38 but each score grade now has a $\pm$A or 10 dB range to allow for the uncertainty in the prediction and scoring processes. The exception, of course, is for the "A" and "F" scores since a S/I ratio which is arbitrarily large (A score) can score no better than "no interference" and conversely. In estimating the likelihood that interference both exists and is damaging to the "ability-to-communicate," Table 6-11 should be used, unless better, or more specific data are otherwise available.

6.6.2 Dynamic EMI Scoring

The word, dynamic, as used here, means a time-changing S/I ratio produced by a scanning antenna system of either the interference source, the offended receiver, or both. The most common case is when either, or both, are radars of the search/surveillance or height finding type.

Dynamic EMI scoring is important in predicting the interference to or from radars since the most pessimistic case (when two radars are momentarily looking at each other) generally exists on the order of only 0.01 percent of the time. When this occurs (generally for a duration on the order of 50 milliseconds), the S/I level may increase by about 60 dB or more. Yet, this "flash-in-the-pan" interference may often be of little or no significance. Therefore, a dynamic (statistical) look at the resulting S/I is necessary if any significant meaning of EMI is to be concluded.

6.6.3 EMI Analysis Sheet

Figure 6-39 depicts the EMI Analysis sheet employed for dynamic EMI scoring. In practice, the procedure for computation is quite straight-forward. Using the EMI Prediction Form, compute the S/I ratio corresponding to the worst possible situation of mutual antenna alignment. This will probably correspond to Condition No. 1 of figure 6-40.

If only one equipment is scanning, then some other condition applies as clarified in Cases B and C of figure 6-40.

The predicted maximum S/I ratios corresponding to one of the three cases depicted in figure 6-40 is entered in Column 3 for the associated condition in figure 6-39. If this worst case should correspond to a S/I ratio of greater than about 0 dB, there is no need to make any further computations since EMI can be assumed to be nonexistent. The percent of time that this S/I exists is then entered under Column 4 and is computed by using the G_0 curve in figure 6-41. The actual entry in Column 4 depends upon which of the three cases in figure 6-40 exists. For Case A, multiply the "percent time" factors corresponding to both transmitter and receiver antennas G_0's, and then multiply the result by 0.01. For either Case B or C enter the percentage directly.

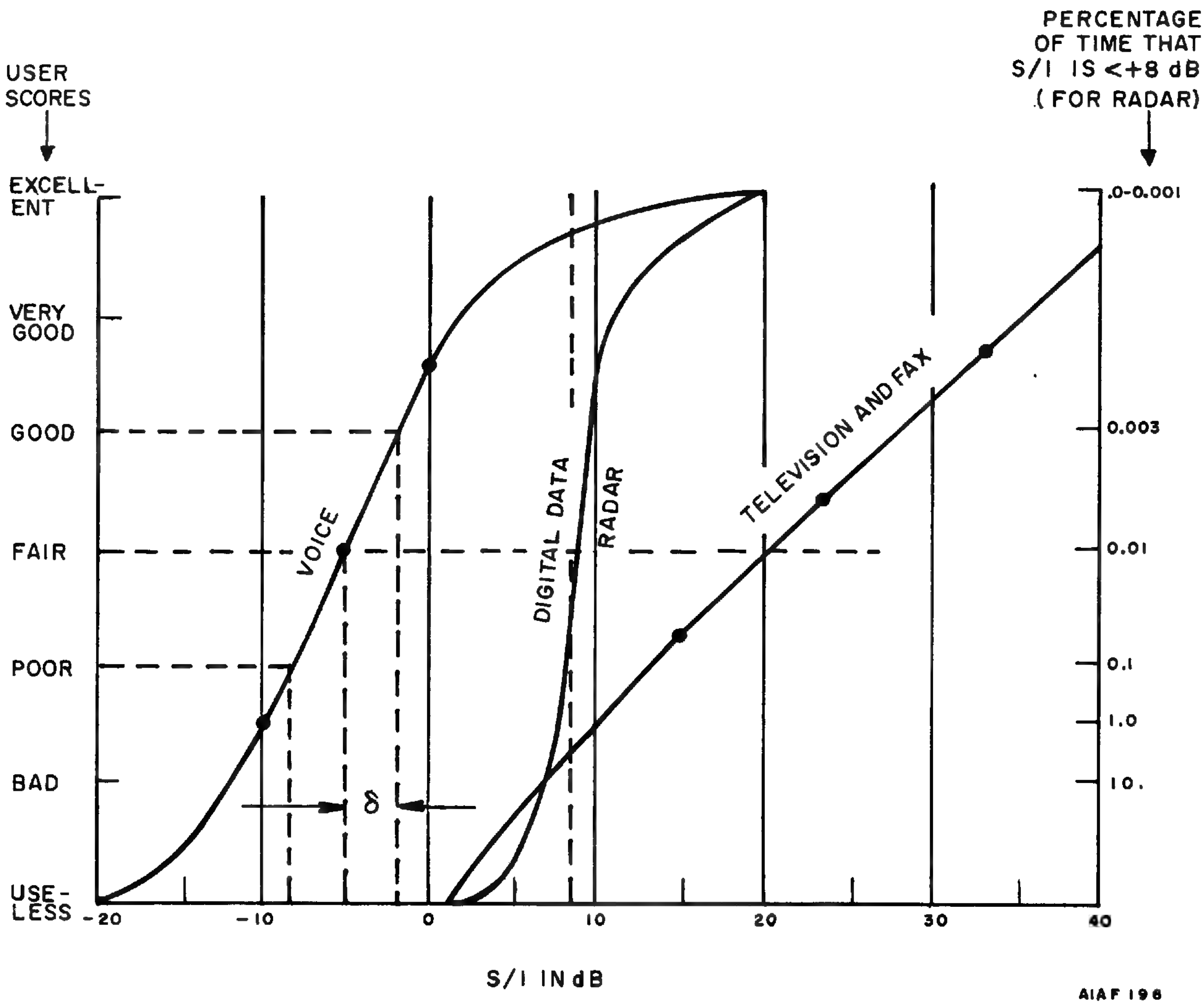

Figure 6 - 38. Nominal User Value Judgments of S/I Situations

1 NO. TX LOBE	2 RX LOBE	3 S/I(dB)	4 %TIME	5 ASCENDING S/I (dB)	6 % TIME	7 RUN TOTAL % TIME
1 MAIN(G_0)	MAIN(G_0)	-60	0.007	-60	0.007	0.007
2 MAIN(G_0)	MAJOR(G_1)	-40	0.03	-40	0.03	0.037
3 MAIN(G_0)	MINOR(G_2)	-28	0.21	-40	0.03	0.067
4 MAIN(G_0)	BACK(G_3)	-18	0.24	-28	0.21	0.277
5 MAJOR	MAIN	-40	0.03	-23	0.70	0.977
6 MAJOR	MAJOR	-20	0.05	-20	0.05	1.03
7 MAJOR	MINOR	-8	0.60	-18	0.24	1.27
8 MAJOR	BACK	+2	0.70	-8	0.60	1.87
9 MINOR	MAIN	-23	0.70	-8	0.70	2.57
10 MINOR	MAJOR	-3	2.00	-3	2.00	4.57
11 MINOR	MINOR	+9	21.40	+2	0.70	5.3
12 MINOR	BACK	+19	24.10	+9	21.40	26.7
13 BACK	MAIN	-8	0.70	+12	2.10	28.7
14 BACK	MAJOR	+12	2.10	+19	24.10	52.8
15 BACK	MINOR	+30	25.00	+30	25.00	77.8
16 BACK	BACK	+30	25.00	+30	25.00	100.0

$G_1 = G_0 - 20$ dB

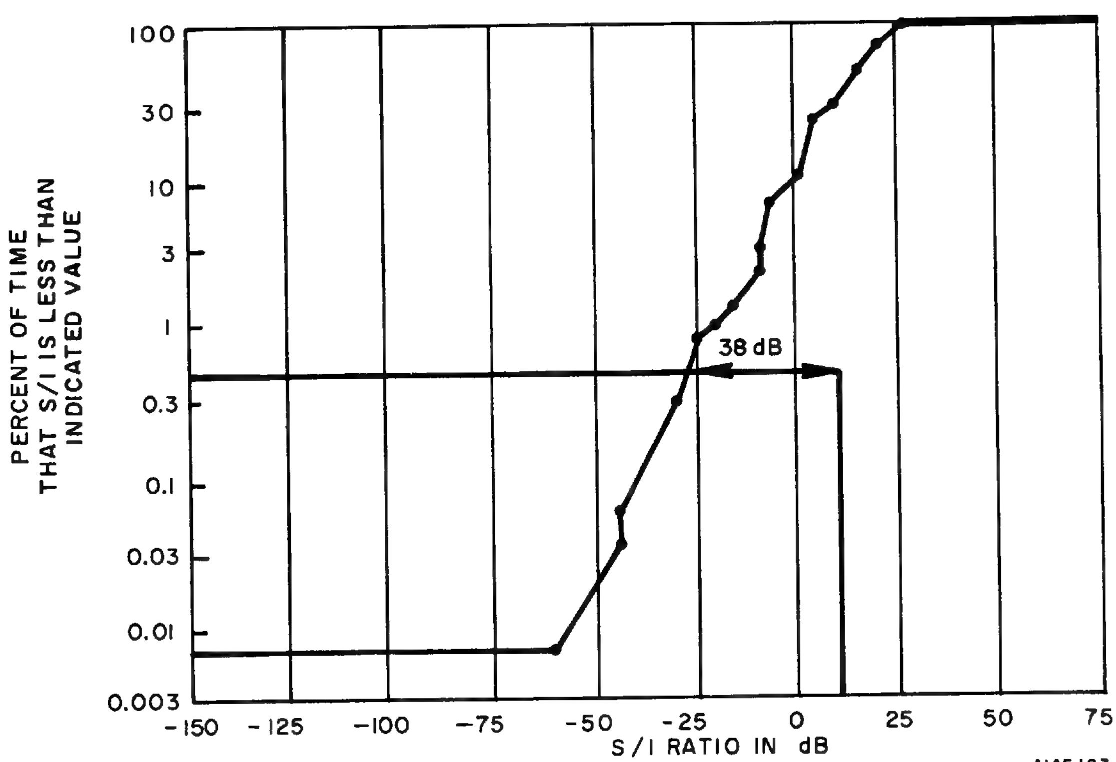

Figure 6-39. Dynamic EMI Analysis Sheet

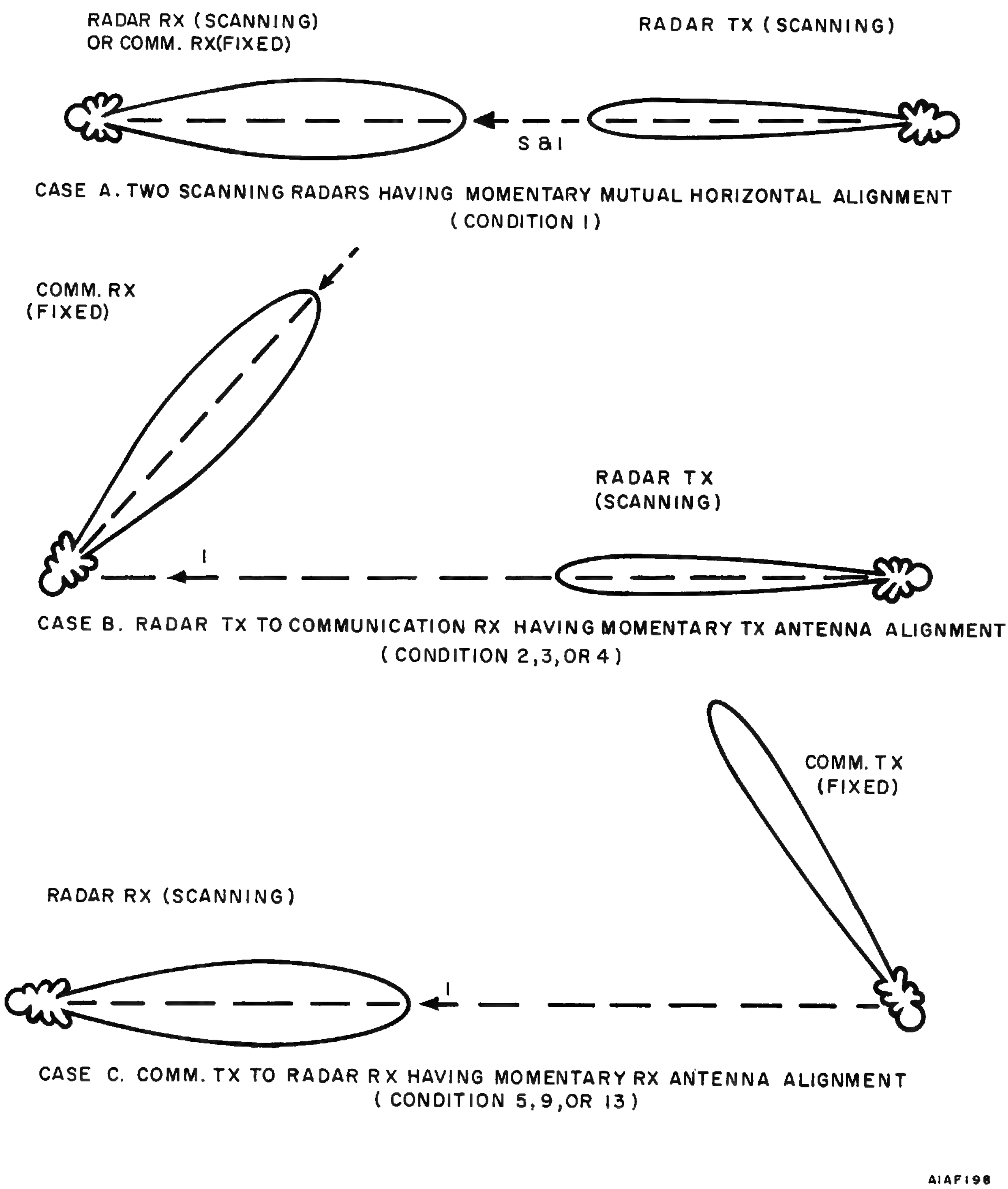

Figure 6-40. Illustrating Three Cases of Worst Antenna Illumination for Computing Maximum S/I Ratio

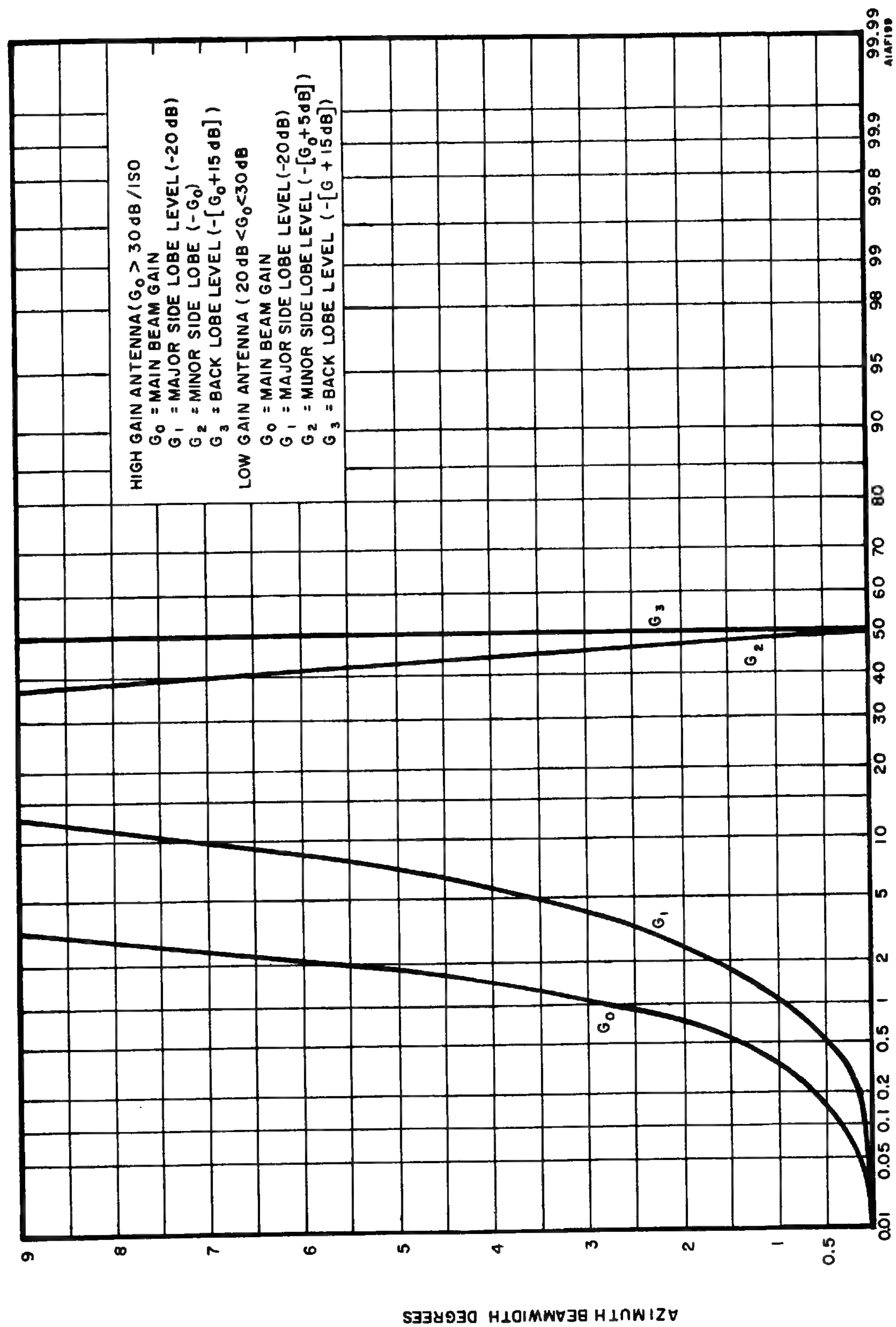

Figure 6-41. Percent of Time Gain Obtains

When the worst case is computed and entered in figure 6-39, the entries corresponding to all other antenna orientations can be linearly projected. This is achieved by reducing the original S/I values as indicated in both figures 6-39 and 6-41. Finally, the corresponding percent time that the different gain combinations exist are picked off figure 6-41, their products formed as before, and the entries made in Column 4 of figure 6-39.

Figure 6-39 has been set up on the basis that each successive S/I value will usually be ascending (values become more positive or less negative). If this is not the case, then Column 5 should be used to transfer Column 3 entries such that every successive S/I entry is ascending. If Column 5 is used, then the associated percent of time entry should be carried over into Column 6. Whether or not Columns 5 and 6 must be used, Column 7 is the running total of Column 4 entries (or Column 6 if this had to be used). The running total is computed by transferring the first entry in Column 4 (or Column 6) into the first entry of Column 7. The second entry in Column 7 is obtained by adding the second entry in Column 4 (or Column6) to the first entry in Column 7. The third entry in Column 7 is obtained by adding the second entry in Column 4 (or Column 6) to the second entry in Column 7. The process is repeated until the last (16th) entry in Column 7 is obtained. This entry should total 100.0% ± 1.0%. If it does not, then the computation should be rechecked for errors.

The graph on the lower half of figure 6-39 for plotting the cumulative percent of time (Column 7) that any S/I level (Column 4 or 6) has been exceeded. From this plot, and from both the system performance requirements and scoring criteria discussed previously it is then possible to determine how much the offending interference must be reduced to make the C-E system meet satisfactory performance. The following example will help to clarify some of these points.

This is an example utilizing the dynamic analysis sheet. Assume a two L-Band scanning radar situation in which the horizontal antenna beamwidths are 1.3^{o} and 4.0^{o} and the relative gains are 37 dB and 27 dB, respectively. Further, assume that the predicted S/I level corresponding to the antennas illuminating each other is -60 dB.

To determine the total percentage of the time a specified S/I level is exceeded, the following computations are made:

a. For transmitter main lobe to receiver main lobe

(1) Enter preceding figure 6-41 at the 1.3^{o} ordinate and read the abscissa (0.5 percent) from the G_o plot.

(2) Repeat for the 4^{o} beamwidth which yields a value of 1.4 percent.

(3) Multiply $(0.5)(1.4) \times 10^{-2} = 0.007$ percent and enter this value in Column 4, Condition 1.

b. For transmitter main lobe to receiver major lobe

(1) Enter preceding figure 6-41 at the 1.3^{o} ordinate and read the abscissa (0.5 percent) from the G_o plot as before)

(2) Enter the 4^{o} ordinate and read the abscissa (5.8 percent from the G_1 plot)

(3) Multiply $(0.5)(5.8) \times 10^{-2} = 0.029$ percent and enter this value in Column 4, Condition 2.

(4) Reduce predicted S/I level by side lobe level (20 dB) and enter this value of -40 dB (-60 + 20) into Column 4.

The process is repeated as shown in figure 6-39. Column 5 is plotted as the abscissa vs Column 7 as the ordinate. All end points are connected by a straight line. The graph in figure 6-39 is extremely useful in determining performance. For example, suppose that the offended radar is reading out blocks of digital words representing target coordinates, velocities, etc. Let it be supposed that the maximum allowable target word error rate for the system redundance involved is one-half percent. This may also correspond to a S/N ratio of about 12 dB in which an error in any character is scored as a word error. Figure 6-39 shows the point location of this required performance.

Figure 6-39 indicates that the required 12 dB S/I ratio is about 38 dB greater than the -26 dB S/I ratio due to the dynamic nature of the scanning process. Therefore, it can be concluded that at least 40 dB of interference rejection must be provided to the culprit source if the offended radar is to be made compatible. The flexibility of using the plot in figure 6-39 is apparent since the required S/I improvement can be readily determined for any system performance specifications.

6.7 APPLICATION OF RESULTS

There are two basic types of EMI problems associated with a Naval Shore Station. The first is the problem of predicting the interference that will result from the installation of new or additional equipment. A different aspect of this EMI problem is the selection of sites on the station which will result in the minimum amount of interference. By applying the EMI prediction technique presented in this report, it is possible to predict the EMI problems that will occur when the equipment is installed. This technique can be used to determine the desirability of the installation, and if the installation is to be made (despite EMI problems) to minimize preparation time for eliminating the problem after the equipment has been put in operation.

The second type of problem is the elimination of EMI situations which currently exist. In problems of this type, the technique will determine the extent of the interference, as well as the source, if it is unknown. By comparing the interference-to-noise ratio that exists at the receiver input terminals with the acceptable signal-to-noise level for the receiver, it is possible to determine the improvement required to eliminate the problem.

This required improvement can then serve as a basis for the selection of the simplest suppression technique that will provide desired improvement. For example, if an improvement of only a few dB is required, the problem may be eliminated by slightly off-tuning the receiver; whereas, if 20 or 30 dB improvement is required it may be necessary to install filters on the transmitter to eliminate the problem.

The following sections provide information to facilitate the application of the prediction technique to the various types of problems.

6.7.1 Siting Considerations

A Naval Shore Station offers relatively little flexibility in the selection of C-E equipment sites; the area is normally small, and the terrain generally level. These factors make it difficult to select sites which will provide interference-free operation of equipment. At most stations installations are already in existence and therefore offer little or no flexibility in determining new sites. For example, VHF/UHF transmitters are housed and located in a specified area and receivers in another. Relocating these sites or a distribution of these sites may prove uneconomical. As a general rule, siting criteria for C-E equipments includes only general references to possible interference from the electromagnetic environment in which the equipment is to be installed, and practically never considers the effect of new installation on existing equipments. The primary stress in the development of the siting criteria should be to obtain the spectrum signature. The lack of electromagnetic environmental considerations is due to the complexity, as well as the spectrum signature variations, existing between equipments of the same class. A lack of electromagnetic environmental considerations is much more serious in the case of installations at Naval Shore Stations, since generally there is a large number of different types of equipment.

The application of the techniques presented in this report to a proposed installation will determine the degree of EMI to be expected. In those cases where several sites are available, this technique can be used to select a site which will minimize the EMI problems. The results of the technique will also provide a measure of the interference which will be experienced by the additional equipment.

In considering the installation of new or additional equipment to a station, the decision is normally based on the assumption that the new equipment will operate near its maximum capability and that the present system will not be affected. The results of the EMI prediction technique will provide those entrusted with making decisions with additional information to make their decision more realistic. For example, it may be desired to install a radar, which will provide longer range and improved coverage capability for the station. By applying the prediction technique it may be determined that, no matter where the radar is installed, it will experience almost continuous interference from a present radar as well as degrade the performance of a large number of communication equipments. This information can then be used to accurately assess the actual advantage that will be gained from the installation of this radar.

It is important to note that the prediction calculations will indicate the level of the interference likely to result. As will be discussed in the next section, it is possible that the potential EMI problems can be eliminated by appropriate suppression techniques. The use of these techniques should be included in evaluating proposed installations.

The advantage of having the knowledge gained by applying the prediction technique before an installation is made should be obvious. In certain cases the installation of the required suppression may be so extensive or costly that an equipment with different characteristics might actually be more desirable. If this is not determined prior to the installation, the suppression will have to be used or the reduced capability of the equipments accepted. Another important aspect is the fact that although there are numerous suppression techniques, many of them require modifications to the equipments or additional hardware be installed. If this is known prior to the installation, a program and schedule for modification may be drawn up so that installation down-time may be kept to a minimum and thus reduce the cost of implementing the technique.

The use of this technique in siting additional equipment at a Naval Shore Station is demonstrated in detail in the examples of EMI discrete prediction techniques.

6.7.2 Recommendations For EMI Reduction

The suppression or reduction of EMI is an extremely complex subject. Techniques to eliminate interference can vary from simply turning off the interfering transmitter to redesigning the receiver. In many cases, particularly in high density electromagnetic environments, such as a Naval Shore Station, the interaction of various equipments requires a decision, whether to reduce or eliminate the interference situations. As mentioned previously, turning off the interfering transmitter will eliminate an EMI situation, but the question arises as to the value of the function provided by interfering equipments when compared with the value of the information lost because of the interference situation.

Another important criterion is the cost of the improvement. Many EMI situations can be eliminated by modifying the equipments involved. In these situations, the decision must be made as to whether the advantages gained by elimination of the situation warrant the cost required to obtain the improvement.

The most efficient method for eliminating interference will depend upon the nature of the situation. In order to select the best technique for a given case, it is necessary to determine the signal-to-interference ratio existing at the receiver input terminals. In those situations where the EMI prediction technique has been utilized the amount of improvement necessary to eliminate the subject EMI can be obtained as follows.

The signal-to-interference ratio will be shown in Line 4.3.1 of the EMI Prediction Calculation Sheet. The value of the signal-to-interference ratio which will give the desired performance, (EMI Highly Improbable) is found in the scoring table in Table 6-11. The improvement necessary, then, is simply the difference between the required signal-to-interference ratio and the calculated signal-to-interference ratio.

In those cases where the presence of EMI is actually determined by the operation of the equipments, it will still be necessary to apply the EMI prediction technique to determine the amount of improvement necessary to eliminate the subject EMI.

The flow diagram shown in figure 6-42 is provided to facilitate the selection of the simplest, most economical means of obtaining the necessary improvement once the necessary amount of improvement has been determined.

As shown on the diagram, the most desirable means of eliminating interference are changes to the receiver which do not involve hardware modifications (block 1). The various possible suppression techniques will be discussed following the explanation of the flow diagram. The next step is to compute Δ_r S/I, the maximum improvement resulting from these changes. The predetermined S/I improvement is compared with the computed Δ_r S/I value (diamond 3) to determine if sufficient improvement has been obtained. If improvement is sufficient ("yes" arm of diamond 3), a best or reasonable trial change is considered (block 4).

The trial change is next examined to see if a frequency change was involved (diamond 5). If no retuning is called for ("no" arm of diamond 5), then the trial change, or changes are offered as a recommended fix. If a change in frequency is indicated ("yes" arm of diamond 5), then, the S/I must be recomputed for other potential EMI sources (block 6), since it is possible to tune out of one EMI situation into another. If no other EMI situations developed ("no" arm of diamond 7) as a result of the recommended tuning, then, the trial change is offered as the recommended fix. If other EMI situations develop ("yes" arm of diamond 7), then new trial receiver changes are made until no new EMI situations develop.

If the "built-in" available Δ_r S/I improvement involving the receiver only with no hardware changes should be inadequate ("no" arm of diamond 3), then quick-fix changes to the culprit transmitter not involving hardware (diamond 8) should be investigated. If simple transmitter changes can be made (block 9), then the new maximum available Δ_r S/I (including effects due to simple receiver changes) should be computed. If the new value of Δ_r S/I is adequate ("yes" arm of diamond 10), then trial changes (block 11), should be made and tested out. If recomputed values of Δ_r S/I are still inadequate ("no" arm of diamond 10), then some fundamental alterations are probably required in the receiver hardware (block 12). These receiver changes are evaluated in terms of their maximum Δ_r S/I as well as their cost and the lead time required. Again the improvement is tested (diamond 3), and the remainder of the program reiterated.

The identification of possible changes in the receiver and/or transmitter is the most critical portion of this method. Changes in the receiver are the most desirable in that they will not affect operation of the other equipments at the station. The simplest receiver change is to detune the receiver slightly off channel away from the interfering signal but still remaining within the transmitters bandwidth. Of course, this being a frequency change, it will require consideration of the possibility that a new EMI situation has been created. The receiver may also be tuned to another channel, but this would require changing the operating frequency of the transmitter radiating the desired signal. This changing of operating frequencies will be covered in more detail at the end of this section.

Another simple change which can provide as much as 4 or 5 dB improvement in some communication cases is to change the receiver antenna height, simply by patching in a similar antenna located higher or lower on the antenna site. The reflected interfering signal, in some cases, may reinforce the direct interfering signal. Thus, by changing the antenna height the geometry of the situation can be changed so that the reflected interfering signal will subtract from the direct interfering signal thereby reducing its strength at the receiver. In this process the desired signal may also be reduced, so the effects of this change should be carefully analyzed before it is applied.

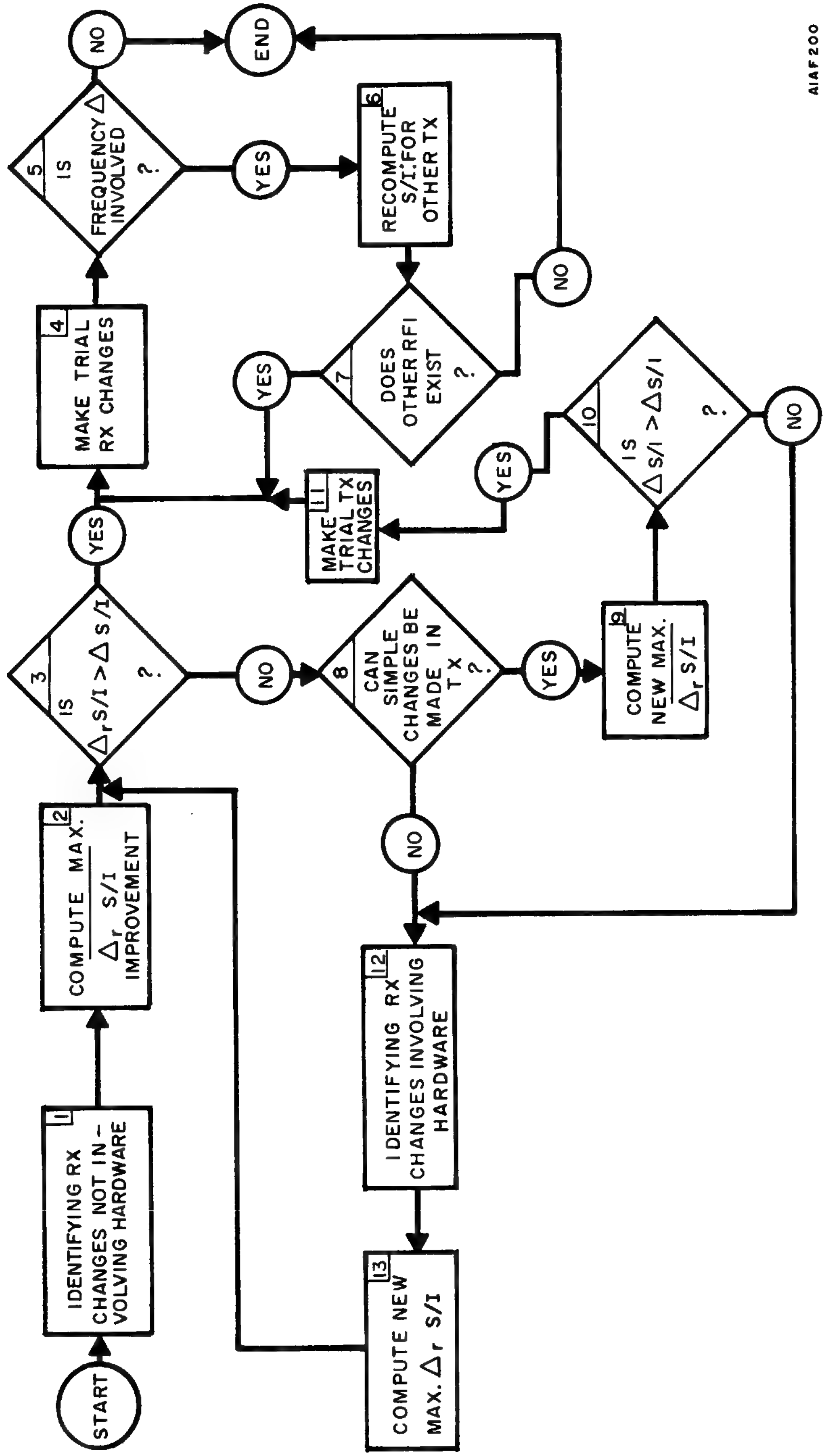

Figure 6-42. General Flow Diagram for Making EMI Correction Recommendations

The use of additional hardware or receiver modifications provide far more flexibility, but these changes must be examined in light of increased costs, and in some cases substantial lead time is required to implement the changes.

Fortunately, in recent years considerable effort has been expended in reducing the susceptibility of both communications and radar receivers to Electronic Counter-measures. Many of the techniques developed are equally applicable to problems of EMI. A radar fix, such as side-lobe suppression, where signals entering the sidelobes are canceled out, would be particularly desirable at a station where the radar is operating among other transmitters.

Other techniques that can be used effectively in certain situations are:

- o False alarm rate detection
- o Pulse width discrimination
- o PRR discrimination
- o Range gating
- o Image frequency preselection
- o Front-end filters

Some interference situations can be eliminated by the use of different antennas. Almost all of the communication antennas in use at Naval Shore Stations are omnidirectional. These antennas have a relatively low gain and allow undesirable signals to enter the receiver from any azimuth. In some EMI situations, it might be possible to employ directional antennas. It would be particularly advantageous for those cases where the source of the desired signal consistently remains in a relatively small azimuth sector. Take, for example, a case where communication is required with aircraft flying a direct route to or from another air station. A directional antenna may be used at long distances until the aircraft is close enough for ground control approach (GCA). The pilot then must change frequency, and the ground receiver operating on the GCA frequency would be patched on an omnidirectional antenna.

Another method of eliminating interference is to utilize cardioid antennas which are omnidirectional except for a null over a small horizontal sector. By aligning this null with the azimuth of the undesired signal the interference may be significantly reduced. In a similar manner to the cardioid, many other shaped beam antennas offer similar solutions.

In considering simple changes there is considerably more flexibility for transmitters than for receivers. The most obvious means of eliminating interference is to turn off the interfering transmitter. In those cases where no feasible means of eliminating the interference exists, the on-the-air time must be shared with other radiating equipment. A decision must be made as to which of the equipments is performing the most important function at the time. If the equipment experiencing the interference is considered to be performing a higher priority function, then the interfering transmitter should go off the air. In those cases where the equipment causing the interference is performing the more important function, then the reverse situation is true. In this case the victim may possibly switch to another channel, or use some emergency means of maintaining communications until the culprit has ceased operating. This would, of course, assume the interference to be of short duration.

In some situations, particularly adjacent channel or harmonic adjacent channel interference, where the interference level is marginal, the problem may be eliminated by reducing the power of the interfering signal. This will, of course, reduce the signal between the interfering transmitter and its receiver, but in some cases the reduction in range will be insignificant compared with the advantage gained by freeing another equipment from interference. In addition to reducing power of the culprit transmitter, the reduction may be accomplished by change of transmitter frequency within the pass-band of the receiver, or by a change of antenna polarization.

The addition of hardware and modifications to the transmitters also can significantly reduce the problem of interference. The main emphasis in this area is the reduction of spurious signals. The use of bandpass filters and low pass filters at the transmitter output will reduce spurious and harmonic radiation to a level which eliminate the effects of interference. In some pulse type equipment is is also possible to round off the pulses and thus decrease the bandwidth of the radiated signal, especially well out into the modulation sidebands.

In the case of radar, or other equipment which employ scanning antennas, cut-outs can be installed which prevent radiation in selected sectors and eliminate some interference situations. This may be done if some loss in coverage can be tolerated. The use of directional antennas can significantly improve the EMI situation.

Figure 6-43 is a form prepared for use with the flow diagram for making EMI correction recommendations. The form contains a summary of the recommendations and a block to enter the results of the improvement from each change made. In most situations the improvement can be obtained from the EMI calculation sheet for a particular situation. It can be seen that any change which decreases a value in the "A" Column (+dB) on the EMI calculation sheet (figure 6-1) or increases a value in the "B" Column (-dB) will decrease the interference to noise ratio (line 4.1, figure 6-1.) The decrease in the interference to noise ratio will be equal to the absolute value of the decrease in "A" or increase in "B". For example, decreasing the radiated power of a transmitter (Line 1.1.5) of figure 6-1 from 100 watts to 50 watts will decrease the transmitter power 3 dB. This is a decrease in the "A" Column (+dB) so the I/N ratio is decreased 3 dB. The size of most Naval Shore Stations is such that the distances between the equipments is in the order of 1 to 3 miles. In these short distances the signal attenuations are usually negligible so that cochannel operation will almost always cause an EMI situation. Interference will usually result when an equipment operates on an adjacent channel or on a harmonic frequency of another equipment. Therefore, the most effective and simplest means of reducing EMI problems is through the careful assignment of frequencies.

The development of frequency assignment plans is beyond the scope of this handbook, but the flow diagram presented for use in the rapid frequency sorting process shows the relationship of frequencies that will probably cause interference.

6.8 HAZARDS EVALUATION TECHNIQUES

6.8.1 The Basic Problem

In paragraph 6.2 a basic interference prediction model was presented as one method of determining the effects of adding equipment to an electromagnetic environment, both upon the equipment itself and upon other equipments existing within the environment. The previous discussion centered upon the interaction between equipments/systems from an interference viewpoint. Some additional questions of equal importance which must be asked during the equipment planning and installation stages are:

o What potentially hazardous situations are created by adding new sources of electromagnetic radiation to an existing site?

o Are any hazardous situations created by changing frequencies or operating schedules of existing equipment?

o What are the potential hazards when adding fuels, ordnance, electronic equipment, and personnel to the vicinity of existing sources of electromagnetic radiation?

o What protective measures are possible, and what is their effectiveness?

The first question contains an important implication, i.e., can the addition of electromagnetic energy by new equipments re-enforce existing radiation levels to create a hazardous situation, where non-hazardous levels existed previously? The answers to these questions may be found by establishment of a hazards analysis or prediction process.

The basic goal of a hazards analysis is to define those areas within a site that may be considered potentially hazardous to both personnel and materiel by presently accepted safe radiation limits. The practical accomplishment of this goal may be realized by a combination of theoretical, "worst case" calculations and on site measurements of EMR power densities at a given site. For the purposes of analysis, the major source of hazardous electromagnetic energy is emitted from the antennas associated with radar and communications equipment of both low and high power emissions.

Min. S/I Improvement Required for Marginal (Score C) performance:__________dB
Preferred S/I Improvement $\geqslant \Delta_r \overline{S/I}$:________dB
Allowable Methods to Improve (S/I): (check appropriate boxes)

1. ☐ Receiver Fixes Not Involving Hardware Additions
   - ☐ Increase Frequency Separation from Δf =________ MHz to________ MHz (Present RX________MHz; New RF__________MHz). Improvement__________dB
   - ☐ Rotate/change RX Polarization Improvement________dB
   - ☐ Antenna Scan Synchronization (TX:__________RPM) (RX: __________RPM)
   - ☐ Sector Blanking (From__________° AZ to __________° AZ) Improvement__________dB
   - ☐ Pulse Synchronize (From ________PRR to ________ PRR) Improvement __________dB
   - ☐ Other:______________________________ Improvement__________dB
   - ☐ Time Share "On-the-Air":______________________________

   Total Improvement in S/I: Δ_1 S/I = ____________ dB

   Is Δ_1 S/I $\geqslant \Delta_r$ S/I ? Yes: No-Go on To No. 2.

2. ☐ Transmitter Fixes Not Involving Hardware Additions
   - ☐ Increase Frequency Separation from Δf =________ MHz to________ MHz (Present TX________ MHz; New Frequency______MHz). Improvement ________ dB
   - ☐ Sector Blanking (From __________° AZ to __________° AZ). Improvement ________ dB
   - ☐ Rotate/change Polarization Improvement ________ dB
   - ☐ Time Share 'On-the-Air" : Improvement ________ dB
   - ☐ Other:____________________ Improvement________ dB

   Total Improvement in S/I: Δ_2 S/I = ____________dB

   Accumulative Improvement: ΔS/I = Δ_1 S/I + Δ_2 S/I =______ dB

   Is ΔS/I $\geqslant \Delta_r$ S/I ? Yes: No - Go on to No. 3.

3. ☐ Receiver Fixes Involving Hardware Additions
   - ☐ Pulse Width Discrimination (__________ μ sec.) Improvement ________dB
   - ☐ PRR Discrimination (____________________PPS) Improvement ________ dB
   - ☐ Band Pass Filter / Preselector Improvement ________dB
   - ☐ Low Pass Filter Improvement________dB
   - ☐ Other:______________ Improvement________dB

   Total Improvement in S/I: Δ_3 S/I = ____________ dB

   Accumulative Improvement: ΔS/I = $\sum_n \Delta_n$ S/I __________ dB

   Is ΔS/I $\geqslant \Delta_r$ S/I ? Yes: No - Go on to No. 4.

4. ☐ Transmitter Fixes Involving Hardware Additions
   - ☐ Harmonic Suppression (Low Pass Filter) Improvement ________ dB
   - ☐ Modulation Sideband Reduction
     - Band Pass Filter Improvement________dB
     - Pulse Rounding Improvement________dB
   - ☐ Other: Improvement ________dB

   Total Improvement in S/I.: Δ_4S/I ______________dB

   Accumulative Improvement: ΔS/I = $\sum_n^4 \Delta_n$S/I ______________ dB

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Figure 6 - 43. Recommendation(s) for EMI Suppression

6.8.2 On-Axis Power Densities

It was previously stated that a large aperture antenna can be characterized by two major regions of radiation called the Fresnel region, or near field, and the Fraunhofer region, or far field. The Fresnel region was defined as that portion of the emitted field lying between a wavelength (λ) from the antenna and a distance given by $2D^2/\lambda$, where D equals the antenna diameter or, in the case of rectangular antennas, the largest linear dimension. The far field region was stated to be that portion of the field extending from the end of the Fresnel region to infinity. The evaluation of on-axis power densities in the far zone is relatively simple since both gain and antenna radiation pattern (or beamwidth in degrees at the half-power points) are independent of the distance from the antenna. Thus, the far field on-axis power density is given by the Friis free-space transmission formula:

$$W_d = \frac{P_t G_o}{4\pi (d)^2} \tag{6-29}$$

where:

W_d = power density at a given on-axis point in mW/cm^2
G_o = Transmitting antenna maximum far-field gain
P_t = Average power transmitted in mW.
d = Distance from antenna to the point in question in cm.

If the gain is not known it may be calculated from:

$$G_t = \frac{4\pi Ae}{\lambda^2} \tag{6-30}$$

where:

A_e = the effective aperture of the antenna and is defined as:

$$A_e = \frac{P_L}{W} \quad \text{meter}^2 \tag{6-31}$$

where:

P_L = Power into the load (watts) W
W = Power density of the incident wave ($watts/m^2$)

Equation 6-29 does not include the effects of ground reflection which, if present, could cause a value of power density that is four times the free-space value. For reflection from smooth earth, as illustrated in figure 6-44, equation 6-29 may be modified by the following expression:

$$W'_d = 4W_d \sin^2\left(\frac{h_t h_p}{14.67\lambda Z}\right) \tag{6-32}$$

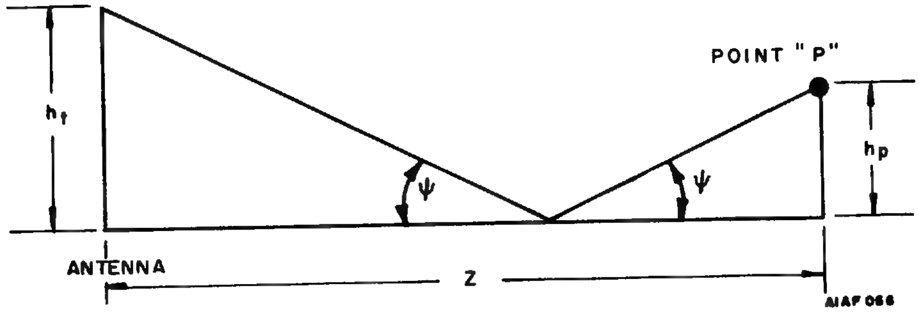


Figure 6 - 44. Smooth-Earth Reflection

where:

W'_d = power density at point p in mW/cm^2
W_d = power density as given by equation 6-29
h_t = antenna height above ground in feet
h_p = height of point p from ground in feet
λ = wavelength in centimeters
Z = distance of point p from antenna in statute miles

Equation 6-32 should not be used for distances beyond the radio horizon and frequencies below 30 MHz. For vertical polarization the grazing angle ψ, as shown in figure 6-44 is limited as follows:

at 100 MHz $\psi \leqslant 1^o$
at 5000 MHz $\psi \leqslant 5^o$

$$\psi = \tan^{-1} \frac{h_t + h_p}{Z}$$

h_t h_p and Z are in same units

As frequency increases, the allowable grazing angle goes up. For horizontal polarization the grazing angle does not restrict the use of equation 6-32.

By substituting W_d = 10 mW/cm2 in equation 6-29, and solving for d_{min}, the minimum safe-on-axis distance for personnel in the far zone may be found. Thus:

$$d_{min} = \sqrt{\frac{P_t G_o}{40\pi}} \quad \text{(cm)} \tag{6-33}$$

$$\text{or } d_{min} = 0.00292 \sqrt{P_t G_o} \text{ feet.} \tag{6-34}$$

where:

P_t = Average power output in mW.

If the peak power output is known, as for radar sets, average power can be determined by multiplying the peak power by the radar duty cycle:

$$P_t \text{ (Average)} = P_t \text{ (peak x d.c.)} \tag{6-35}$$

where:

$$\text{d.c.} = \text{duty cycle} = \frac{\text{Pulse Width (msec)}}{\text{Pulse Train Period (msec)}}$$

$$= \text{Pulse width x pulse repetition frequency.}$$

In the Fresnel region, antenna gain and pattern are no longer constant, with both parameters being functions of the distance from the antenna. On-axis power densities may be calculated as follows:

a. Large Aperture Rectangular Antennas. For this type of antenna, a gain correction factor may be found which depends on the distance from the antenna and the type of illumination, or energy distribution across the antenna aperture. Curves of such correction factors are given for common illuminations in figures 6-45 through 6-49, with the antenna maximum linear dimension plotted as a parameter. If the type of illumination is not known, it may be estimated by the following process:

Calculate a constant R defined by:

$$R = \frac{\pi \theta_H H}{180 \lambda} \text{ or } \frac{\pi \theta_V V}{180 \lambda} \tag{6-36}$$

where:

θ_H = Beamwidth at half power points in H direction in degrees

θ_V = Beamwidth at half power points in V direction in degrees

H, V correspond to horizontal and vertical antenna dimensions

λ = Wavelength in same units as H and V

Once R has been calculated, table 6-12 may be used to estimate the illumination. Note that the table is based on the assumption that the H and V illuminations are separable.

Table 6-12. Rectangular Apertures

LIMITS OF R	ESTIMATED ILLUMINATION
$0.88 \leqslant R < 1.2$	Uniform
$1.2 \leqslant R < 1.45$	Cosine
$1.45 \leqslant R < 1.66$	Cosine^2
$1.66 \leqslant R < 1.93$	Cosine^3
$1.93 \leqslant R < 2.03$	Cosine^4
ILLUMINATION	**F_h OR F_v**
Uniform	1,000
Cosine	0.810
Cosine^2	0.667
Cosine^3	0.575
Cosine^4	0.515

A check on the validity of the estimated aperture illumination can be made by computing the antenna efficiency from its illumination constants. This is done by making use of the fact that the far field gain of a rectangular aperture antenna with separable distributions is given by

$$G_o = \frac{4\pi A F_H F_V K}{\lambda^2} \tag{6-37}$$

where:

- A = Physical area of aperture
- λ = Wavelength in same linear units as A
- F_H = Correction factor depending on H direction illumination
- F_V = Correction factor depending on V direction illumination
- K = Efficiency

The correction factors, F_H and F_V, depending on illumination, are given in table 6-12.

Rearranging equation 6-37 we have, for the antenna efficiency:

$$K = \frac{G_o \lambda^2}{4\pi A F_H F_V} \tag{6-38}$$

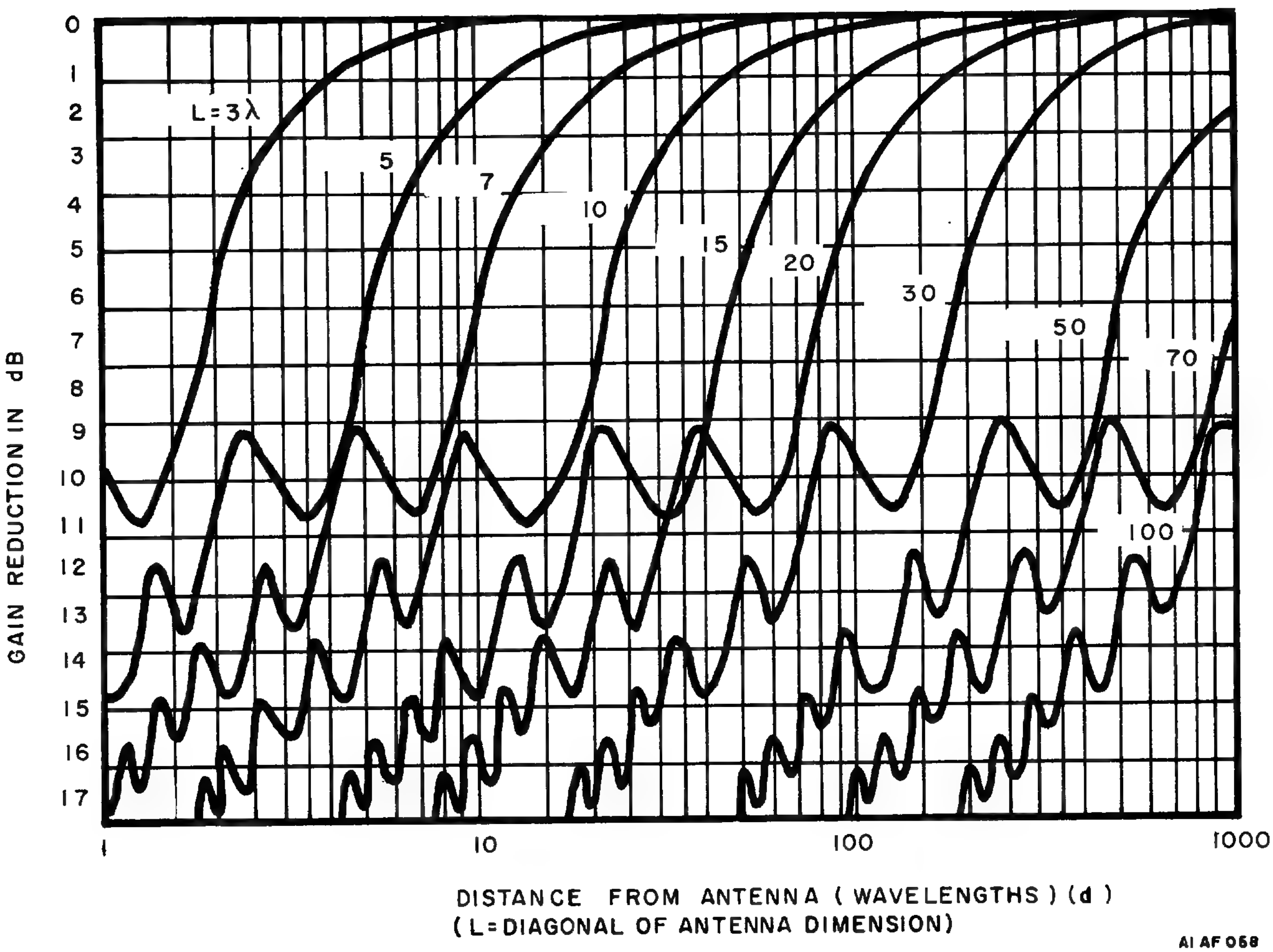


Figure 6 - 45. Fresnel-Region Gain - Correction for Uniform Illumination

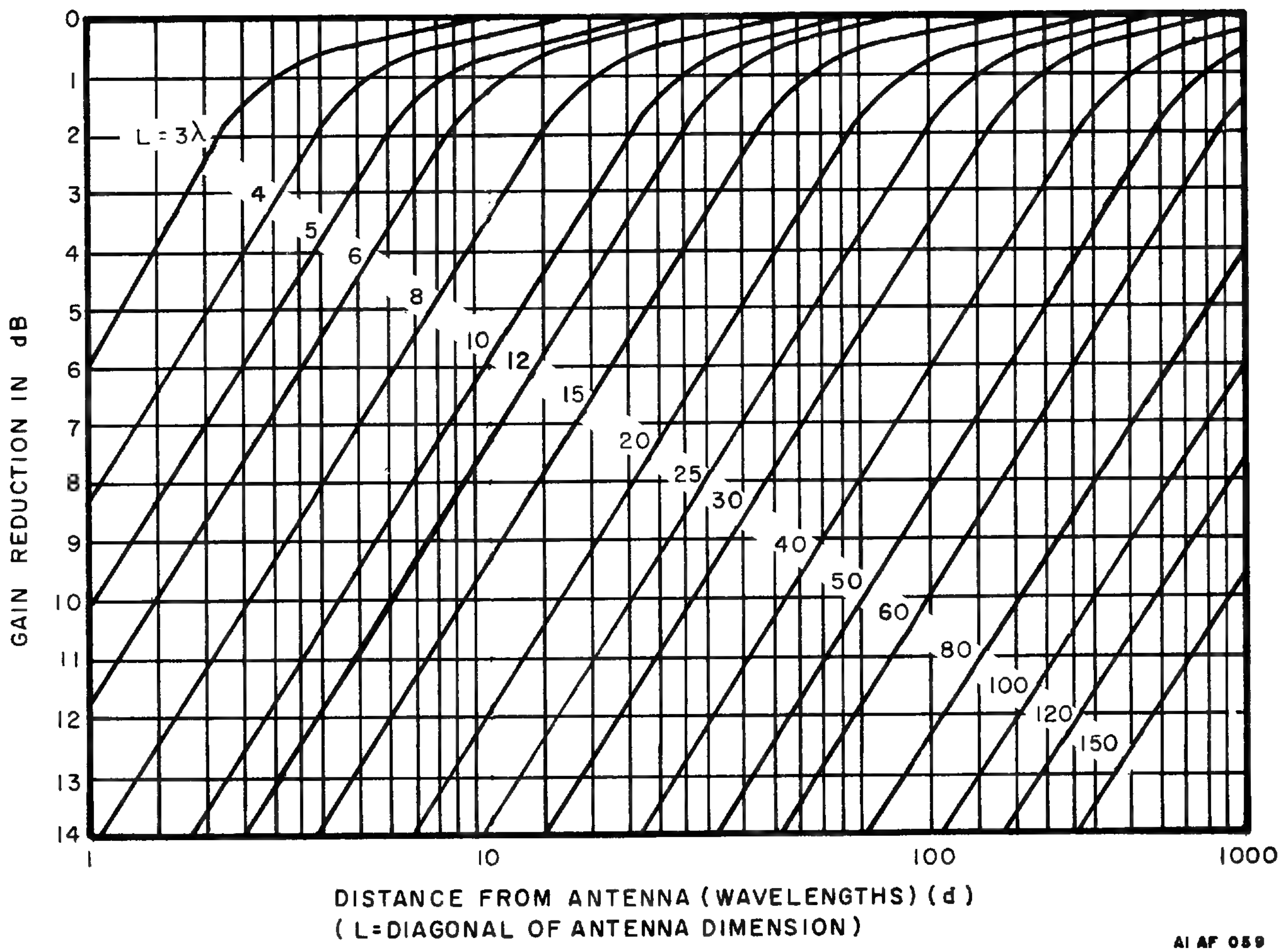


Figure 6 - 46. Fresnel-Region Gain - Correction for Cos Illumination

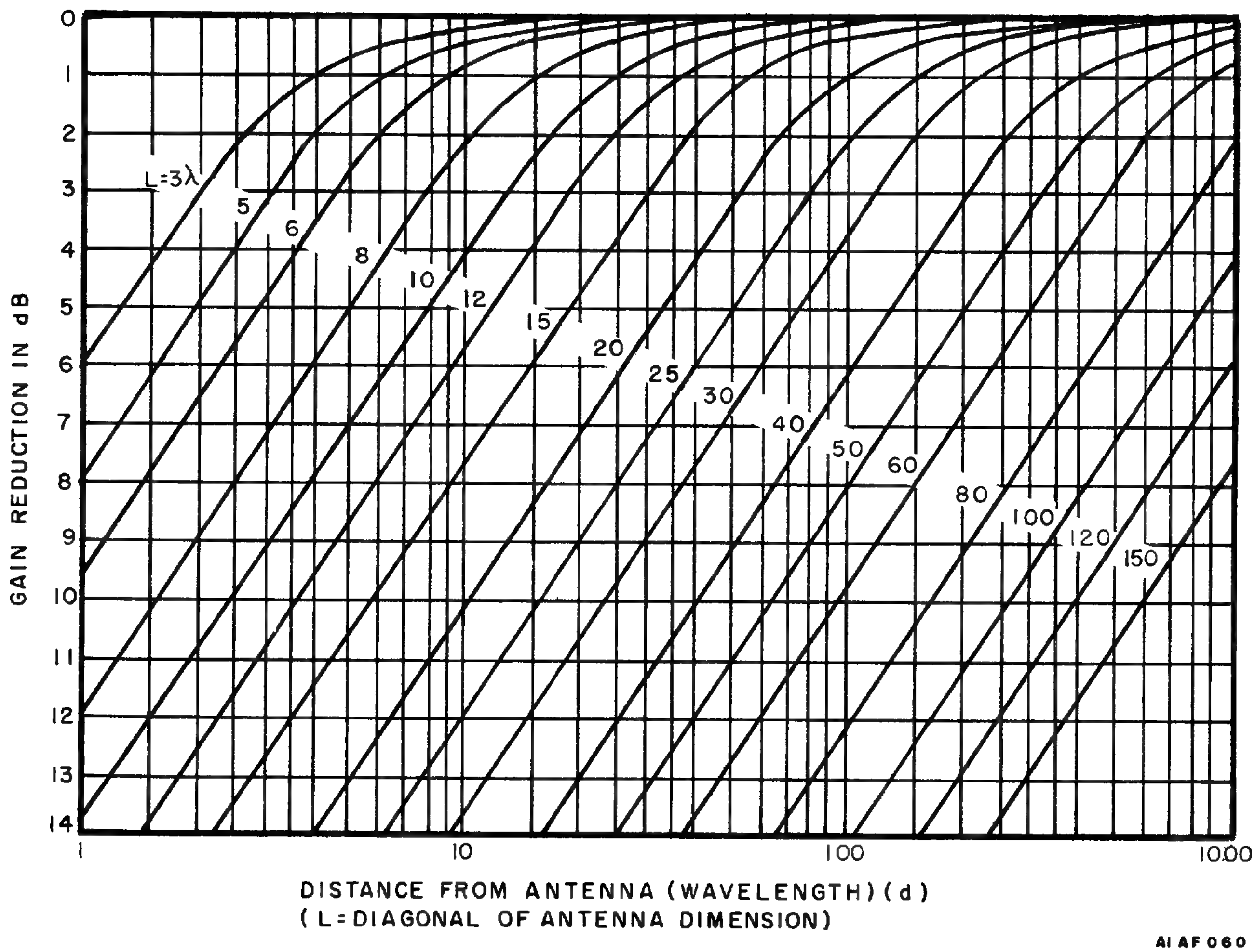


Figure 6 - 47. Fresnel-Region Gain - Correction for Cos^2 Illumination

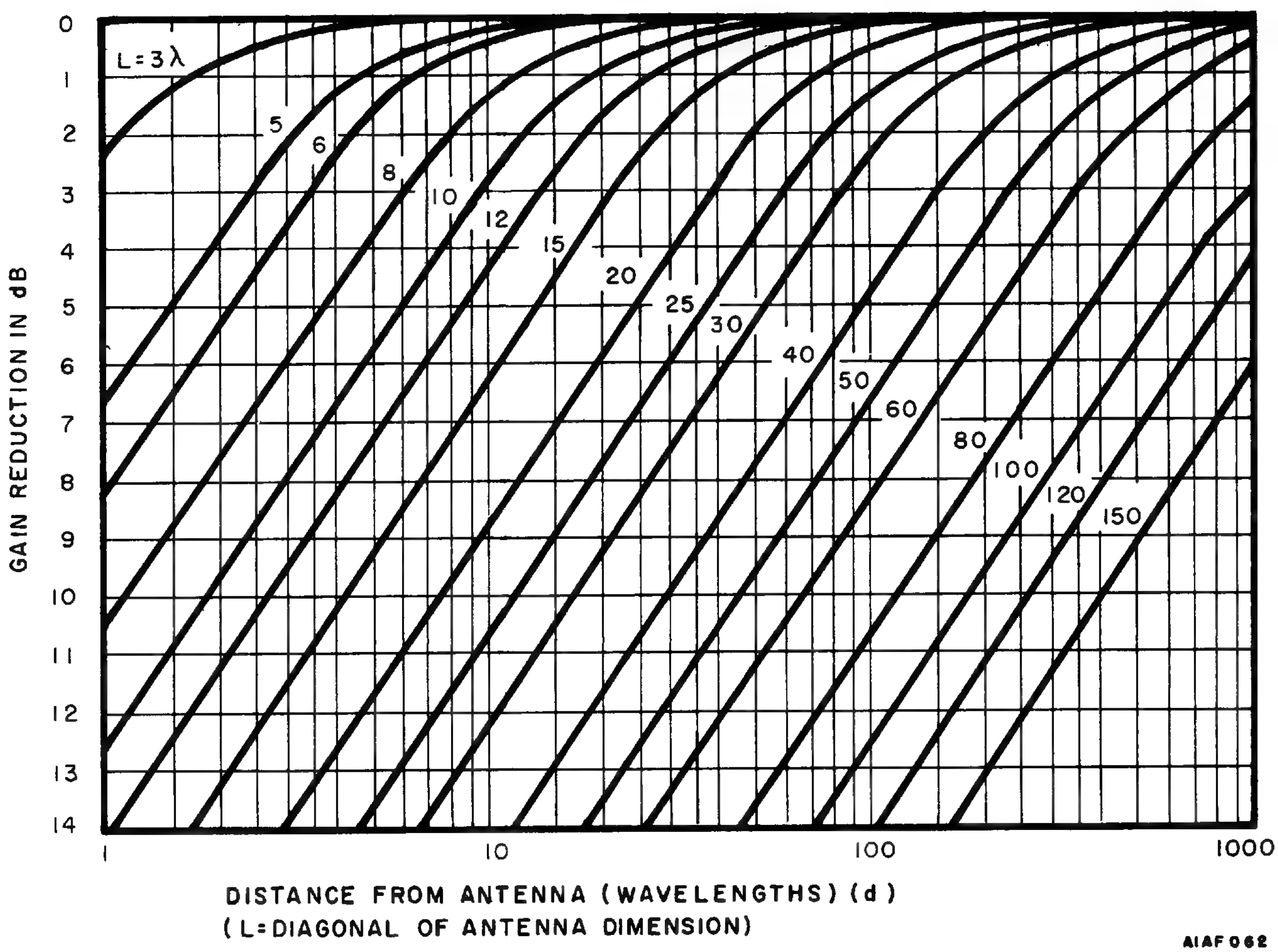


Figure 6 - 48. Fresnel-Region Gain - Correction for Cos^3 Illumination

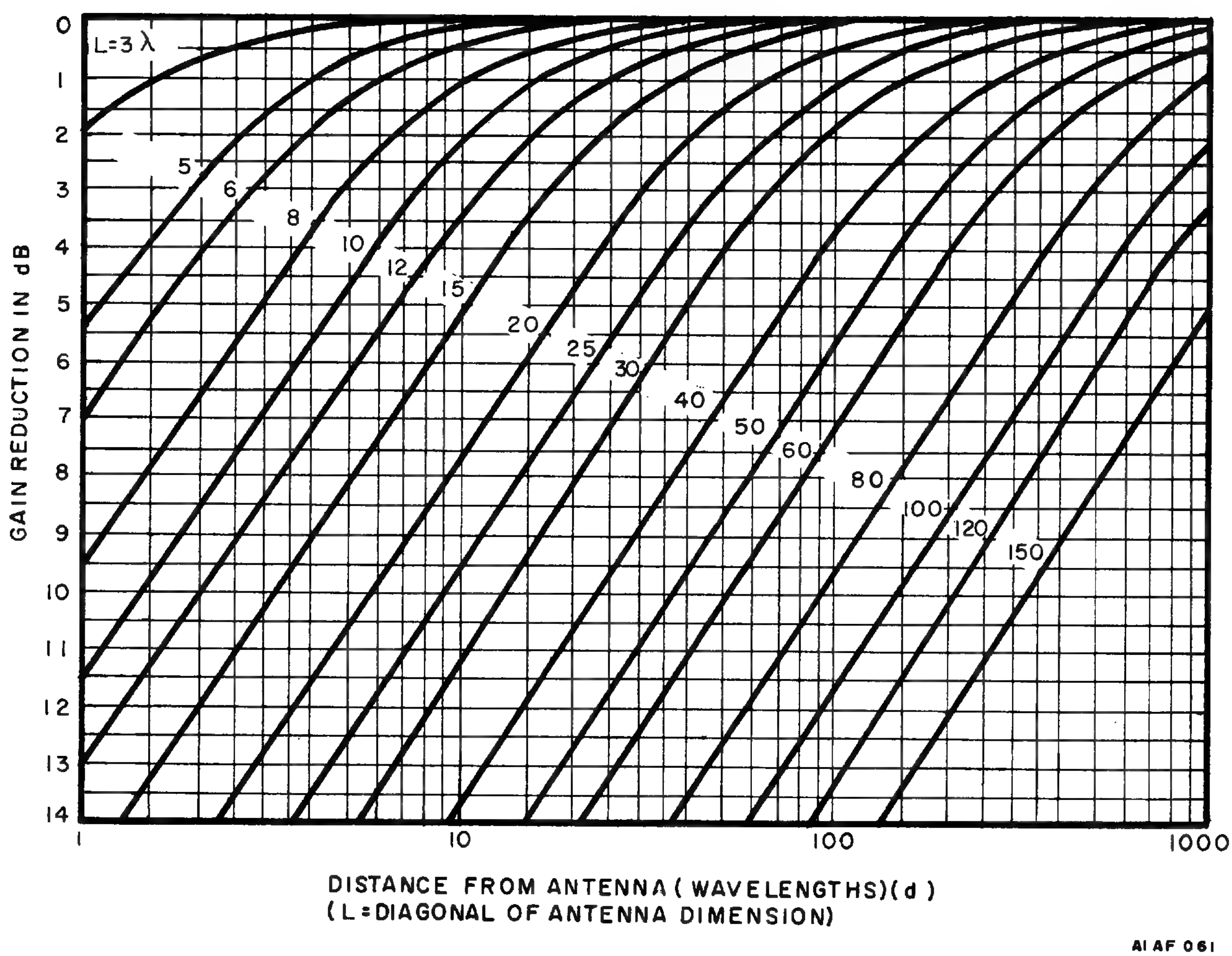


Figure 6 - 49. Fresnel-Region Gain - Correction for Cos^4 Illumination

If the computed efficiency is reasonable, then it is safe to assume that the aperture illuminations determined as above are satisfactory. A reasonable criterion for efficiency can be given as $0.5 \leqslant K \leqslant 0.9$.

When the constant R is found to be on the borderline between two orders of illumination, the higher order should be selected initially since this will give a higher (and more hazardous) power density. If this choice causes the efficiency to be too high, then the next lower order should be used.

Once the aperture illuminations have been estimated for both vertical and horizontal illuminations, and checked to be plausible, the Fresnel region gain corrections may be found from the appropriate figures 6-45 through 6-50. The two correction factors are then subtracted from G_o, the far field gain to give the gain in the Fresnel region. Power density is then obtained from:

$$W_d = \frac{P_t G_f}{4\pi d^2} \quad (\text{mW/cm}^2) \tag{6-39}$$

where:

G_f = Corrected far field gain

b. Large Aperture Circular Antennas. Calculation of power densities in the Fresnel region for this type of antenna follows the same general procedure as given for rectangular antennas. After R has been calculated, table 6-13 is used to estimate the illumination. The efficiency is then calculated as a check on the illumination using the appropriate value of F from the table in equation 6-38. Power density at a given on-axis point within the Fresnel region is given by the free-space, far field formula multiplied by an appropriate correction factor. The correction factor is found in the chart given in figure 6-50.

Table 6-13. Circular Apertures

LIMITS OF R	ESTIMATED ILLUMINATION
$1.02 \leqslant R < 1.27$	Uniform
$1.27 \leqslant R < 1.47$	$(1-r^2)$ taper
$1.47 \leqslant R < 1.65$	$(1-r^2)^2$ taper
$1.65 \leqslant R < 1.81$	$(1-r^2)^3$ taper
Greater than 1.81	$(1-r^2)^4$ taper
ILLUMINATION	**F**
Uniform	1.00
$(1-r^2)$ taper	0.75
$(1-r^2)^2$ taper	0.56
$(1-r^2)^3$ taper	0.44
$(1-r^2)^4$ taper	0.36

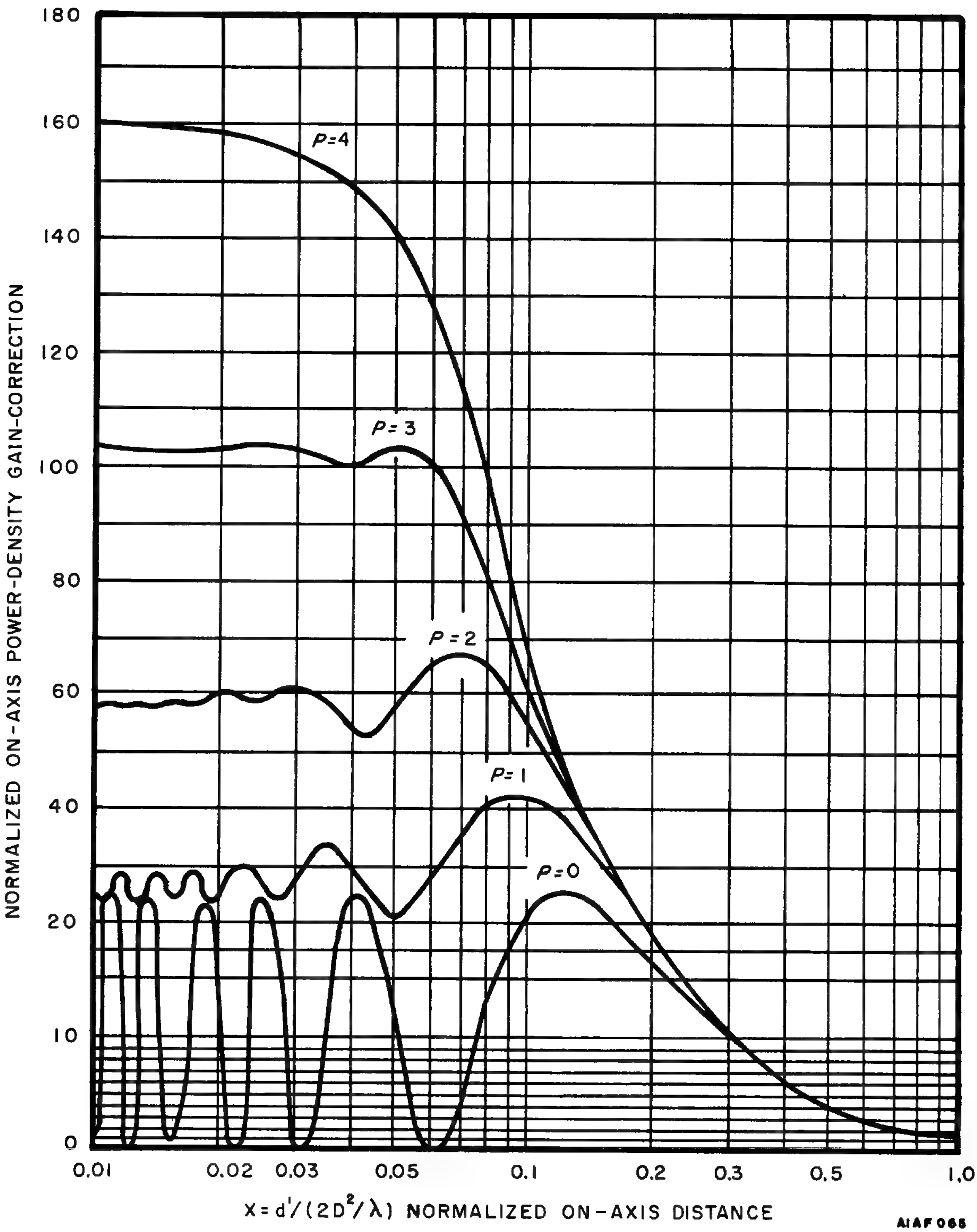


Figure 6 - 50. Normalized On-Axis Power-Density Curves for Circular Aperture $(1-r^2)^P$ Tapers

Calculate the distance to the end of the Fresnel region by using $2D^2/\lambda$, where D equals the antenna diameter. Divide d, the distance from the antenna to the point of interest, by the value found for $2D^2/\lambda$, to give the normalized on-axis distance: this is the parameter plotted as the abscissa on the graph shown in figure 6-50. The correction factor is then obtained from the curve plotted for the previously estimated type of illumination.

6.8.3 Off-Axis Power Densities

The exact calculation of power densities off the main beam axis is a complex mathematical task, since such calculation must "predict" the exact three-dimensional nature of the radiation pattern, including significant side and rear-lobe structures whose shapes are dependent upon such parameters as antenna structural variations, type of construction, aperture feed phase errors, and the presence of obstacles near the antenna.

For circular aperture antennas having $(1\text{-}r^2)$ taper, an approximate solution for the secondary pattern power-density contours is given by: (see figure 6-51).

$$W_r = W_d \cos^2 \left[\frac{1.27\,D}{\lambda\alpha} \tan^{-1} \frac{r}{d} \right] \tag{6-40}$$

where:

- W_r = Power density at a point off the main beam axis - (mW/cm²)
- W_d = Power density on the beam axis at the point of connection of the normal from the off-axis point (d). - (mW/cm²)
- D = Antenna diameter (feet)
- λ = Wavelength (feet)
- α = A Fresnel region connection factor (numerical)
- r = Distance normal to antenna axis from off-axis point (feet)
- d = Distance from antenna aperture along main axis (feet)

W_d may be found from:

$$W_d = 26.1 \frac{P_t G_o}{4\pi d^2} \left[1 - \frac{16x}{\pi} \sin \frac{\pi}{8x} + \frac{128x^2}{\pi^2} \left(1 - \cos \frac{\pi}{8x}\right) \right] \tag{6-41}$$

where:

$$x = \frac{\lambda d}{2D^2}$$

The beam broadening factor α is given by:

$$\alpha = \pi / 16x \sqrt{1 - \frac{16x}{\pi} \sin \frac{\pi}{8x} + \frac{128x^2}{\pi^2} \left(1 - \cos \frac{\pi}{8x}\right)} \tag{6-42}$$

By rearranging equation 6-40 and letting W_r = 10 mW/cm², the safe distance power density envelope is found:

$$r = d \tan \left[\frac{\lambda\alpha}{1.27} D \cos^{-1} \sqrt{\frac{10}{W_d}} \right] \tag{6-43}$$

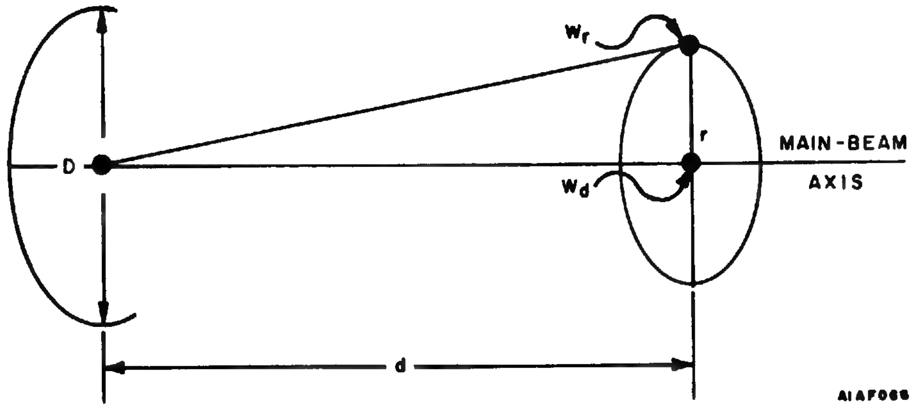


Figure 6 - 51. Calculation of Off-Axis Power Densities for Circular Aperture, 1-r^2 - Taper Antennas

Figure 6-52 is a nomogram which may be used for quick solutions of both on-axis and off-axis safe distances. Investigation of the preceding equations reveals that there is a direct relationship between off-axis safe distances and transmitted average power over a range of aperture diameter from about 10 to 150 wavelengths.

6.8.4 Ordnance Power Transfer

A worst case analysis may be obtained for electroexplosive devices by treating the lead-in wiring to an EED bridge as a linear antenna and determining the induced current under ideal RF energy transfer conditions. Such an analysis necessarily omits those protective measures which are normally present in a weapons system, e.g., shielded wiring and shielded enclosures. For mathematical analysis of power transfer problems see NAVWEPS OD 30393 and NAVAIR 16-1-529. Blasting caps may be analyzed in a similar manner. See ANSI C-95.4.

6.8.5 Equipment Power Transfer

The analysis of RF energy transfer to C-E equipments may be accomplished in a manner similar to that previously outlined for ordnance. Because of the multitude of equipment types with each having its own particular damage threshold, and because of the many modes of energy transfer, a general solution is not possible. Instead, a worst-case configuration may be assumed and the energy coupled to the equipment determined. For example, assume that a piece of transistorized equipment is connected to some other equipment by a poorly shielded cable two meters long. Under worst-case conditions the cable may be viewed as an antenna operating into a matched load, and having an effective aperture of about two square meters at the VHF/UHF bands. Assume that the cable is exposed to a radar RF field having a power density of 5 mW/cm^2 and a pulse repetition rate of 200 pulses per second. The energy collected per pulse is then given by:

$$E = \frac{A_e W_t}{f} \text{ (joules)} \tag{6-44}$$

where:

E = Energy per pulse
W_t = Average field power density in watts/m^2
f = Pulses per second
A_e = Effective area in meter^2

Therefore,

$$E = \frac{2 \times 50}{200} = 0.5 \text{ joules.}$$

Since typical burnout levels for semiconductors are of the order of 10^{-6} to 10^{-4} joules on a single pulse basis, the calculation reveals a potentially hazardous situation.

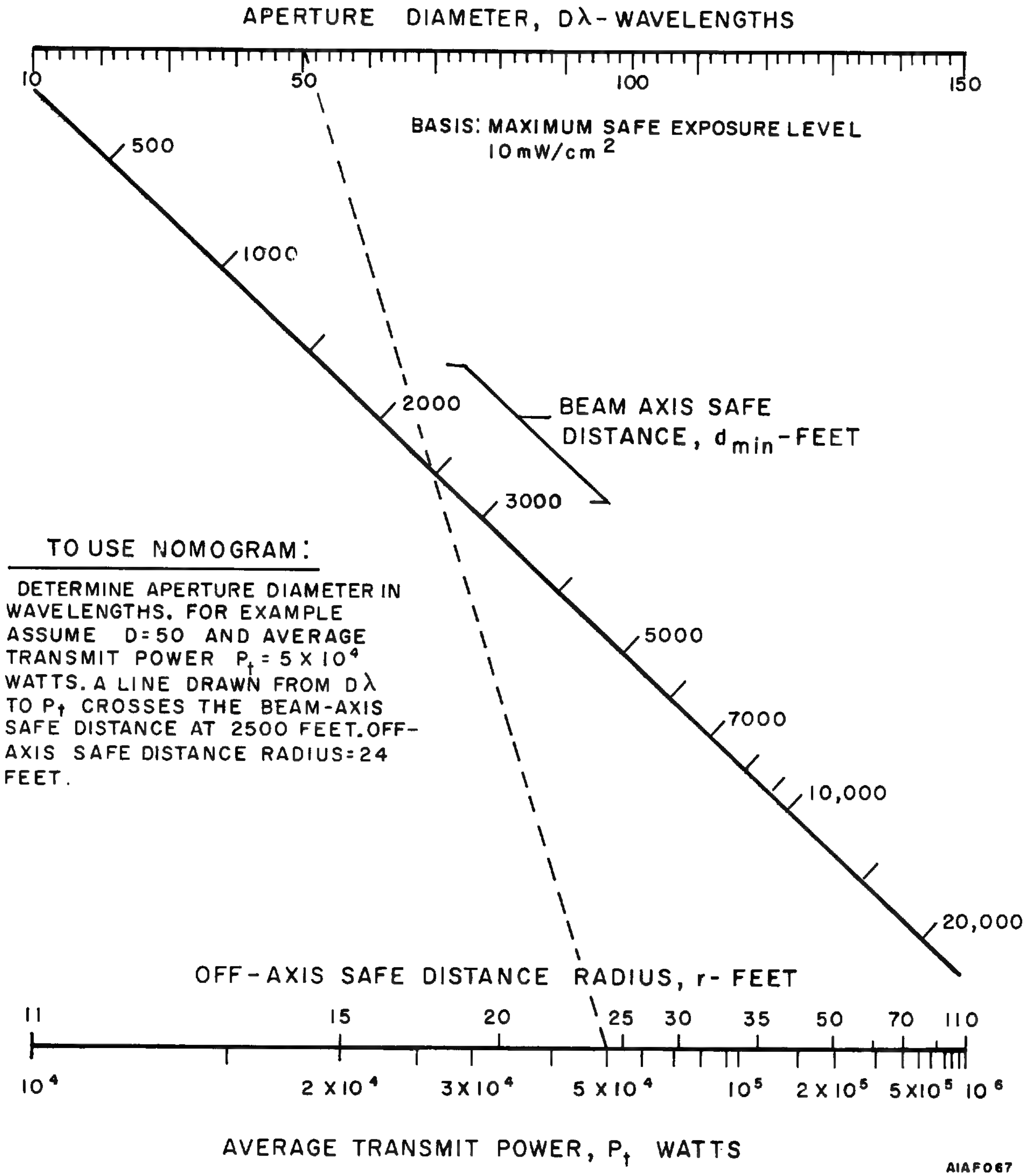


Figure 6 - 52. Microwave Radiation Safe-Distance Nomogram

CHAPTER 7

BASIC INSTALLATION CONSIDERATIONS

7.1 BASIC CONSIDERATIONS

The prevention or minimization of potential interference situations may be accomplished by various suppression techniques applied at either the source of the unwanted emissions, during the transmission stage, at the receiving (susceptible) equipments, or some combination of the three.

The ideal way of dealing with potential interference is by preventing or minimizing the generation of unwanted energy at the source; obviously if no potentially interfering emissions are generated, then no problem exists. Also, since an energy source can affect multiple equipments via a combination of radiated and conducted emissions, and because it is much more difficult (and costly) to suppress unwanted energy at susceptible equipments, suppression emphasis should be placed at the source.

Since it is not possible to prevent all potentially interfering signals from being generated or transmitted, the installation planner must sometimes devise measures to minimize the effects of undesired emissions that may gain entry into a device. Table 7-1 summarizes the areas which should be evaluated if an EMI problem is observed. Close attention to such factors as siting, grounding, bonding, shielding, and filtering during the installation planning stage will aid materially in achieving EMC and in reducing EMR hazards.

7.2 SITING

Siting is the term applied to the location of communications-electronics equipment within a given area to meet operational requirements. Implied within this definition is the achievement of optimum performance by siting to prevent or minimize the creation of potential interference situations.

In site planning, the individual equipment characteristic must be considered to obtain the optimum layout, i.e., is the equipment a fixed communications station? If so, is it a receiving facility or transmitting facility? What is the operating frequency, that is, is it UHF, VHF, etc.? Are transmitters and receivers to be located at the same site? Are rotating antennas used, as in search radars? What are the operational requirements? These, and many other factors will determine the final arrangement.

7.2.1 General Considerations

Surveys are made to determine suitability of a particular site for installation of electronic equipments. The following items are of interest from an EMC and hazards viewpoint, as well as an operational requirements viewpoint. Many other items are required for a complete survey.

a. Maps available of area showing general location of site (for example, state and county maps) attached to report.

b. Topographic maps of site area when available.

c. Site maps.

o A site map, to scale, showing the technical space requirements and proposed locations of antennas, transmission-line runs, electric and telephone outside-plant cable, and buildings.

Table 7-1. Evaluation of Equipments Determined to be Sources or Victims of EMI

A. CIRCUITS TO BE SHIELDED AND FILTERED

- o Have the following EMI producing circuits been filtered in the EMI sources?

  a. Chopper
  b. Converters
  c. Inverters
  d. Relays
  e. DC motors
  f. Switches
  g. Clock or timing circuits with fast rise time or high repetition circuits
  h. Other circuits

- o Have transformer-rectifier (TR) outputs been filtered; was the transformer electrostatically shielded?

- o Has bandpass filtering been used on transmitter outputs or receiver inputs?

- o What type of electromagnetic field is being shielded against, E field or H field? Is the shielding material suitable for this type of field for the frequency range of interest?

- o Have decoupling capacitors been used on internal power connections?

- o Have any feed-through capacitors been used for internal connection of circuits? Or, as bulkheadmounted headers?

- o Have shielded subassemblies been used?

- o Have RF chokes and inductors been used to confine the RF energy to the desired circuits?

- o Were parts of internal chassis of equipment used to obtain shielding?

- o Have waveguide-below-cutoff techniques been used for chassis openings, such as tuning adjustments or air cooling?

- o Have low-level or susceptible circuits been physically separated from EMI producing circuits within an enclosure?

- o Have toroids been used to minimize the leakage field of inductors? Have inductors been cross-oriented to minimize coupling?

Table 7-1. Evaluation of Equipments Determined to be Sources or Victims of EMI (Continued)

B. METHODS OF ELIMINATING SPURIOUS EMANATIONS AND RESPONSES

- Are components being operated in linear rather than nonlinear regions, if possible?
- Are crystal-controlled circuits being used? Has the best choice of multiplier stages been made?
- Have crystal filters, bandpass filters, tank circuits, tuned stages, and other narrowband devices been used?
- Have RF trap circuits been used for known or expected spurious outputs or responses?
- Have circuits been used which inherently discriminate against creation or passage of certain harmonics, such as push-pull outputs of amplifiers, balanced mixer-ring coupler combinations, or other hybrid circuits of a similar nature?
- Have circuits of balanced or symmetrical design been used?
- Have diodes or other biasing devices been used to establish definite minimum or maximum actuation levels for circuits?
- Have coincidence circuits, time-delay circuits, or similar logic circuits been used ?
- Have circuits using coded inputs or outputs been used ?
- Has filtering been done at subsystem levels, especially multiplier stages?
- Have RF circuits been decoupled from power supplies?
- Have short-lead lengths been used in RF circuits? Has internal wire routing been controlled?
- Has physical and electrical isolation of equipments and potentially capable of producing or of being susceptible to spurious energy been achieved?
- Are internal subassemblies shielded and filtered to prevent undesired modulation?
- Have components and devices been chosen to minimize frequency drift or random modulation due to temperature, aging, vibration, etc?
- Are potentially susceptible equipment and circuits sufficiently shielded against external RF fields, including low-frequency magnetic fields?
- Have special precautions been taken to prevent responses at receiver image frequencies?
- Have shielded antenna inputs been used?

Table 7-1. Evaluation of Equipments Determined to be Sources or Victims of EMI (Continued)

- o Have operating frequencies been chosen to avoid conflicts with known existing frequencies or their harmonics?

- o Have the proper or excessive power levels of generated frequencies been used, such as the local oscillator stages or receivers or multiplier and output stages of transmitters?

- o Has circuitry (other than RF) of receivers and transmitters, such as power connections, telemetry connections, and monitoring points, been controlled to prevent RF coupling to other circuits?

- o Have any special methods been used to avoid spurious modes of operations of circuit elements, such as klystrons and oscillators?

C. METHODS OF ELIMINATING SPURIOUS RESONANCES

- o Have short-lead lengths been used where possible?

- o Has damping been used in circuits capable of oscillation?

- o Have feed-through capacitors been used for inter-stage coupling and isolation, and for power input connections to RF circuitry?

- o Have waveguide-below-cutoff techniques been used where possible?

- o Has the number of enclosures openings been minimized?

- o Have critical dimensions been avoided, considering the enclosure or subenclosure as an RF cavity?

- o Have tuning methods which minimize nodes or harmonic generation been used?

- o Have all feedback loops been designed to prevent oscillation under worst-case conditions?

- o Have high-power and low-power stage of units been isolated?

- o Is the bonding adequate at the known critical radio frequencies?

- o Have component tolerances been controlled to prevent frequency drift, mode switching, etc., due to temperature, aging, etc?

- o Have RF components been used throughout RF stages, (i.e., have components been used that are not self-resonant in the intended frequency range, unless desired)?

Table 7-1. Evaluation of Equipments Determined to be Sources or Victims of EMI (Continued)

C. METHODS OF ELIMINATING SPURIOUS RESONANCES

- o Have special circuits which discriminate against spurious resonance been used?

D. METHODS OF OBTAINING CONTINUOUS SHIELDING ON EQUIPMENT USING PRESSURE OR HERMETIC SEALS

- o Have the equipment enclosures been mechanically designed to assure sufficient pressure between mating parts?
- o Have the equipment chassis been mechanically designed to minimize the number of openings and open leakage?
- o Has each opening in equipment enclosure been analyzed to determine the need for gaskets, waveguide-below-cutoff techniques, screening, etc?
- o Has the minimum attenuation needed by the enclosure been evaluated?
- o Are openings and attenuation consistent? If not radiation through the metallic portion of the enclosure will occur, leakage will normally determine minimum overall enclosure leakage, except at low frequencies.
- o Do the mating surface pressure, area, finish, or tolerances degrade the expected attenuation of the enclosure seams?
- o Have dissimilar metals been used in the installation, is this compatible with the expected environment?
- o If RF gaskets have been used, is the design adequate to optimum pressure, class of joint, or seam, choice of gasket mounting, size of gasket, attenuation of gasket, etc?
- o What are the expected internal and external electromagnetic fields and frequencies?

E. THICKNESS OF CASE MATERIAL REQUIRED TO PROVIDE ADEQUATE SHIELDING IN HIGH POWER RF EQUIPMENT

- o Are there expected internal and external fields and frequencies? What is the physical location of the equipment to other equipments?
- o Is the enclosure thickness adequate to attenuate the expected fields to a tolerable level ? Is the thickness and weight excessive?

Table 7-1. Evaluation of Equipments Determined to be Sources or Victims of EMI (Continued)

E. THICKNESS OF CASE MATERIAL REQUIRED TO PROVIDE ADEQUATE SHIELDING IN HIGH POWER RF EQUIPMENT

- How is the estimated additional attenuation to be provided?
- Is composite shielding provided by enclosure, sub-enclosure, waveguide-below-cutoff openings, gasket seams, screened openings or normal making surfaces?
- Does associated external cabling degrade the required attenuation levels?

F. SELECTION OF INTERFERENCE-FREE COMPONENTS TO BE USED WITH OTHER COMPONENTS

- Are diodes or other suppression components being used across relay coils?
- Are RC circuits being used across switch or relay contacts?
- Are solid-state switches being used instead of mechanical switches?
- Are capacitors being used directly across DC motor brushes?
- Are electrostatically shielded transformers being used?
- Are matched diodes being used in balanced mixers?
- Are toroids or other low leakage field inductors being used?
- Are nonself-resonant components, such as feed-through capacitors, being used?
- Are bulkhead-mounted components being used?
- Are crystal filters being used?
- Are separate connectors being used for sensitive and EMI producing circuits?
- Are twisted pair, twisted triad, or shielded wire being used?
- Is balanced-circuit design being used?
- Are diodes or other bias devices being used to establish definite maximum or minimum actuation levels?
- Are connectors being used as inherent parts of filter?
- Are crystals being used as frequency sources?
- Are selective waveguide or coaxial components, such as diplexers, being used?

Table 7-1. Evaluation of Equipments Determined to be Sources or Victims of EMI (Continued)

F. SELECTION OF INTERFERENCE-FREE COMPONENTS TO BE USED WITH OTHER COMPONENTS

- Are lossy line techniques being used to attenuate harmonics?
- Are temperature-compensated components being used to minimize drift, etc?
- Are components being operated in linear regions?
- Are limiting devices, such as diodes, being used?
- Are DC blocks being used?

G. OTHER PERTINENT INFORMATION

- Are there any special type circuits which intentionally or unintentionally eliminate or minimize EMI? Examples might be blanking circuits, time-sequencing circuits, disabling circuits, bridge or differential type of circuits, balanced input circuits, possibly AGC,AFC, and AVC circuits.
- Is there any bonding information that has not been previously covered?
- Is there any circuit uniqueness due to special signal or modulation characteristics?
- Is there any antenna data that could be included which could influence the EMI characteristics of transmitters or receivers?
- Is there any sharing of antennas, or time sharing, or switching of antennas? If so, has it been proved feasible.
- Are there any transmission line or antenna devices present, such as RF isolation, whose losses or bandwidth would be pertinent?
- Have sources of primary power been fully covered? Are there any usual characteristics of primary or secondary power sources?
- Is there any circuit redundancy which might affect EMI control?
- Have the most susceptible equipments and circuits been identified? Have the greatest EMI producing equipment and circuits been identified?

o Additional maps as required showing locations of the transmitting and receiving antennas with respect to the reflection zones.

.d. Photographs of the site may be required to illustrate unusual features or special problems.

e. Reflection terrain profiles, as may be indicated.

f. Tidal or seasonal water-level data and analysis of its effect on site adequacy in the case of water reflection terrain.

g. Horizon profiles taken from the antenna and from other locations as required to define situations where horizon- clearance angles may be a problem.

h. Elevation angle of the horizon at design azimuth and an estimate of distance from site to the obstruction.

i. Profiles and other data needed to establish suitability of local radio-relay paths.

j. Ambient noise or interference estimate, or report of measurements.

k. List of radio, radar, and television frequencies in use, or proposed for use, in the immediate area. Distances and antenna directivities, transmitting and receiving facilities, output-power levels.

l. Interaction with radar, direction-finding equipment, VHF omnidirectional range, tactical air-navigation systems, or radio beacons.

m. Estimate of seasonal influences likely to affect suitability of the site.

n. Any problems of compatibility with existing facilities. Examples are:

o Noise, hum, and frequency response of telephone lines.

o Terminal facilities:teleprinter speeds, station battery voltage, and available capacity levels for voice inputs and outputs.

o. Technical factors relating to the adequacy of the site, particularly with respect to sources of emissions and potential signals interference and, when appropriate, requirements for communications between sites and traffic control centers. This should summarize conclusions with respect to the overall technical adequacy of the proposed site.

7.2.2 Detailed Considerations

Detailed siting criteria for communications equipment may be found in Naval Shore Electronics Criteria Handbooks NAVELEX 0101,102; 0101,103; 0101,104; and 0101,105. Siting criteria for other electronic systems will appear in an appropriate volume of the Criteria Handbook Series when it is published.

7.3 GROUNDING ELECTRONIC SYSTEMS

The basic purpose of earth ground is, in general, to hold electrical and/or electronic equipment at or near earth potential. This in turn, provides for the required safety of personnel and, if properly designed, improves the operation and continuity of service of all electronic configurations. Considering all the variables, it is practically impossible to design an earth grounding system which can be used as a standard.

7.3.1 Requirements Of A Satisfactory Ground Connection

A ground connection, regardless of its application, must meet certain specifications. The electrodes, buried in the ground to form an electrical connection to earth must themselves be good electrical conductors and be capable of resisting corrosion while in contact with the soil. In addition, the electrodes must be capable of withstanding mechanical abrasion and have sufficient area in contact with the soil so that the ground resistance is within the rated limits. The resistance of this earth path must remain reasonably constant throughout the seasons of the year and must be unaffected by the circulating currents resulting from the equipment configuration to which the connection is made. In short, ground connections should be durable, have low DC resistance, low AC impedance, sufficient current carrying capacity, and of such design that provides for ease of installation and maintenance.

7.3.2 Factors Affecting Earth (Soil) Resistivity

The range of earth resistivity may vary from several ohms/cm^3 to several million ohms/cm^3. This variation is due to the electro-chemical action in the soil and is dependent upon the moisture and temperature, as well as the composition of the soil.

a. Effects of Soil Composition. The most general data on earth resistivity considers the type of soil and not the environmental conditions. Data collected by the National Bureau of Standards listed in Table 7-2 indicates a wide variation in soil resistivity dependent upon the composition of the soil. This table demonstrates that a ground connection that might be satisfactory in one type of soil would be totally inadequate in soil of another composition. Samples taken from different locations of similar soil composition, when measured, have sometimes varied by a factor of 200 to 300 percent.

Table 7-2. Resistivity of Different Soil Composition

SOIL	RESISTANCE (OHMS) 5/8 in. x 5 ft. RODS			RESISTIVITY ohms/cm^3		
	Avg.	Min.	Max.	Avg.	Min.	Max.
Fills, ashes, cinders, brine, waste	35	14	41	2370	590	7000
Clay, shale, gumbo, loam	24	2	98	4060	340	16300
Same-with varying proportion of sand and gravel	93	6	800	15800	1020	135000
Gravel, sand stones, with little clay or loam	554	35	2700	94000	59000	458000

b. Effects of Environmental Changes on Soil Resistivity. Variations of soil resistivity with moisture are important since what might have been considered an excellent ground connection might become, due to fluctuations of moisture content with the changing seasons, a high resistance ground connection that would compromise the ground system. Dry soil has such a high resistivity that it functions as an insulator. The effect of moisture upon soil resistivity is illustrated in figure 7-1. The resistivity increases abruptly between 10 and 20 percent with a slight decrease in moisture content. Table 7-3 illustrates the variations of resistivity in two dissimilar samples of soil as the moisture content is increased. The resistivity of the samples vary greatly until, with 30 percent moisture content, one sample measures 6,400 ohms/cm^3 and the other 4,200 ohms/cm^3. As important as moisture content is, it is not always the predominant factor in determining low resistivity of soil. A ground rod driven in the bed of a mountain stream in which the water is devoid of organic and inorganic impurities would not conduct readily and would introduce a high resistance connection between the electrode and earth. Unless the soil contains sufficient soluble mineral elements to form a conducting electrolyte, an abundance of moisture will not provide the soil with adequate conductivity.

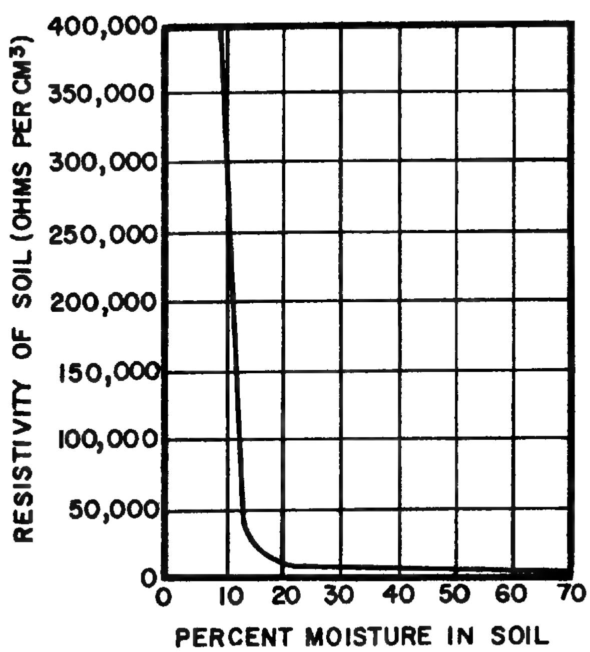


Figure 7 - 1. Resistivity vs. Moisture Content for Red Clay Soil

Table 7-3. Variations of Resistivity in Two Dissimilar Samples of Soil

PERCENT MOISTURE CONTENT (per cm by wt)	RESISTIVITY ohms /cm^3	
	Top Soil	Sandy Loam
0	Over 1 billion	Over 1 billion
2.5	250,000	150,000
5.0	165,000	43,000
10.0	53,000	18,500
15.0	19,000	10,500
20.0	12,000	6,300
30.0	6,400	4,200

Ambient temperature is another environmental change that will influence soil resistivity. This is graphically illustrated in figure 7-2. As the temperature approaches the freezing point of water, the resistivity of the soil increases sharply. Consequently, it would be suspected that soils with high moisture content would be particularly troublesome if the temperature falls below the freezing point for an extended period of time. These two variables - temperature and moisture are part of the seasonal environmental changes; their effects work simultaneously as the seasons change. Figure 7-3 relates these changes over a period of 18 months. Also note that these reactions are more prevalent on the surface of the soil.

7.3.3 Earth Connection Design Considerations

In order to provide a low impedance ground connection for any ground system, a study of local soil characteristics is mandatory. The standard equations used to determine the effectiveness of a ground electrode or the electrode resistance to earth assume a uniform soil structure in contact with the electrode to the depth driven. The resistance of an earth connection will be that offered to current flow within six to ten feet surrounding the electrode (see figure 7-4). Ninety percent of the current distribution into the soil is within this area. Tests conducted by the National Bureau of Standards have shown that the contact resistance between the electrode and the soil can be considered negligible when compared to the resistivity of the soil itself.

a. Current Loading Capacity. A ground connection is a resistance connection mainly confined to the volume of earth immediately surrounding the electrode. As ground current flows through the ground electrode, heat is generated that follows the I^2R heat loss pattern. Like all resistors, this ground connection can be damaged if excessive current is passed through it for an appreciable length of time. The heating effect causes the temperature of the soil surrounding the electrode to rise, drying out the soil. The loss of moisture causes the electrode contact resistance to rise and, consequently, there is a reduction in the current dissipation rating of the connection. When selecting a particular ground electrode configuration, it is important to achieve as low a contact resistance as cost factors will permit. For ground currents that will flow for a relatively long duration, soil conditions alone control the current capacity. When designing the ground configuration for employment of this type, is must be appraised only in terms of desired resistance.

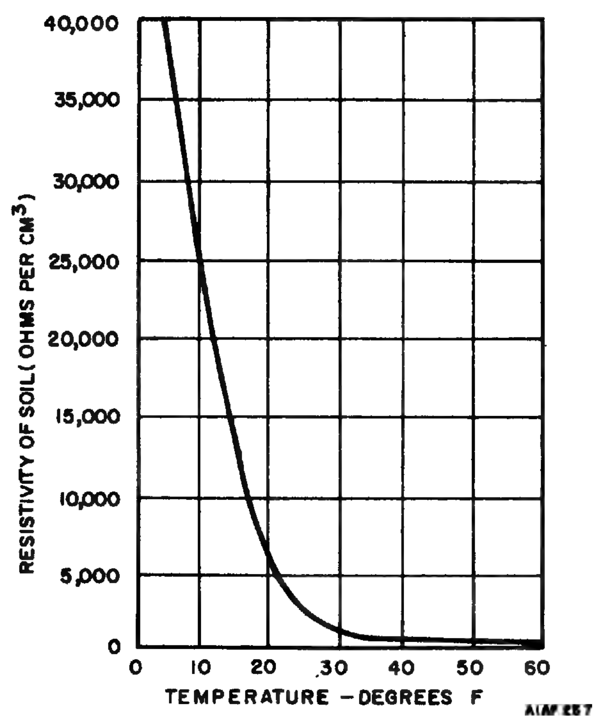


Figure 7 - 2. Variation of Soil Resistivity with Temperature

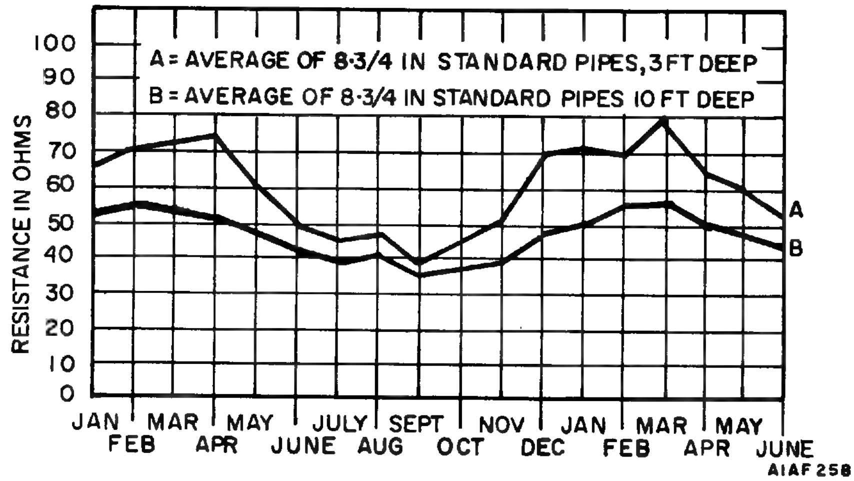


Figure 7 - 3. Variation in Resistance of Pipe Grounds with Months

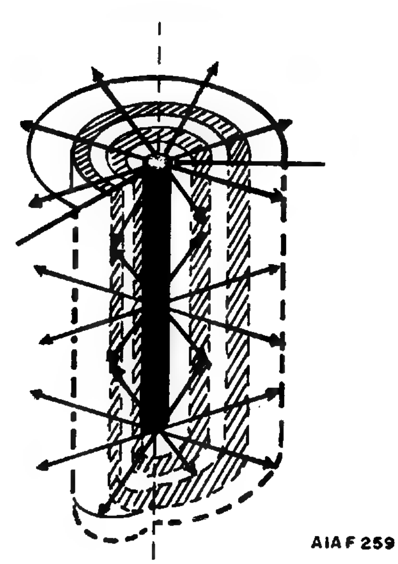


Figure 7 - 4. Current Distribution About a Ground Electrode in Earth

b. Variations of Ground Impedance with Frequency. Grounding systems are inherently dependent on the frequency of energy to be dissipated into the earth. At 60 hertz and low frequencies, the impedance is generally resistive and a good electrode to earth contact is all that is required to provide adequate grounding. As frequencies go higher the reactive term becomes the predominant and controlling factor. At frequencies below 5 kHz, capacitance exists between the buried ground electrode and the surrounding soil. If alternating current is impressed on the electrode, the resultant current will have a "leading" component whose contribution to impedance is slight at low frequencies. As the frequency increases, the leading component becomes of greater importance. The "leading" component of current will increase as the capacitance between the buried electrode and the surrounding soil increase; this capacitance is a function of the surface area of the electrode and the resistivity of the soil encompassing it. The curves of figure 7-5 disclose the inverse proportionality between impedance and frequency. In both configurations the slopes decrease to a point where no appreciable change in impedance with increase in frequency is evident. Additional investigations revealed that increasing the lengths of the ground rods did not produce any marked decrease in impedance.

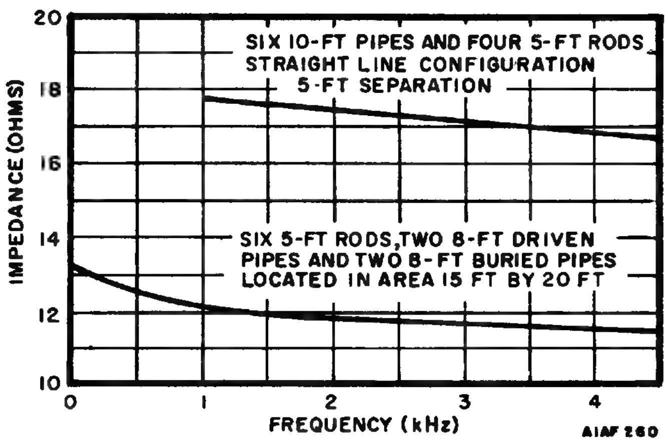


Figure 7 - 5. Relation Between Impedance to Ground and Frequency for Two Multiple Rod Connections

c. Soil Conductivity as a Function of Depth. In the design of a grounding system local soil characteristics must be considered. Empirical data shows that soil structure varies as a function of depth. The surface soil is usually dry and, more or less, nonconducting depending upon the amount of precipitation for a given area. Below the topsoil there is a stratum of semi-moist soil of a different texture, and finally, at some depth, a lower level of permanent moisture known as the water table. In many localities not only does the moisture vary at these levels but the texture of the soil changes radically. Figure 7-6 depicts the relationship of conductance to resistance as a function of depth. The resistivity of the soil varies with a change in depth below the surface because of the two variables previously discussed, (temperature and moisture) as well as the composition and the physical position of the soil in the various layers. The conductance (reciprocal of resistance) is plotted to show a more meaningful relationship as the depth of the ground rod is measured. It will be noted from these curves that the sharp increase in conductance, after 30 feet, is attributed to ambient climatic conditions no longer affecting this parameter. It can readily be seen that many of the factors that affect soil conductivity are directly related

and dependent upon each other. Some adverse characteristics can be overcome simply by increasing the depth to which the electrode is driven. This, in turn, will improve the contact resistance for the following reasons:

(1) The area of contact between the electrode and soil increases in proportion to the length of the electrode below terrain surface.

(2) Soil resistivity stablilizes with depth when the permanent moisture content is increased.

(3) The changes in resistance resulting from temperature variations are less likely with increased depth.

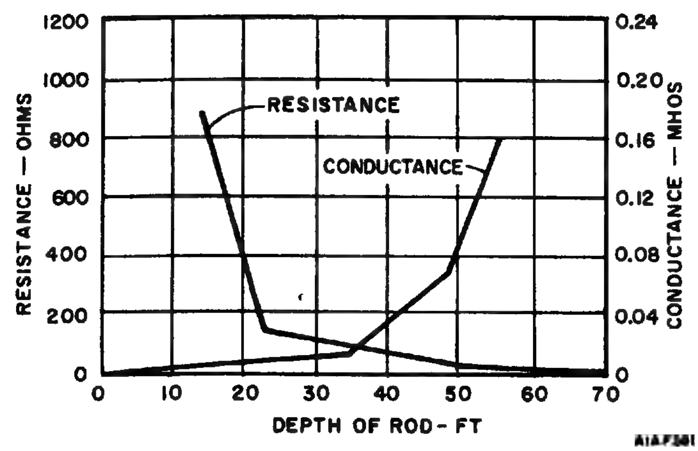


Figure 7 - 6. Resistance and Conductance Curves as a Function of Rod Depth

7.3.4 Types and Characteristics of Ground Electrodes

Ground electrodes are basically divided into two general categories. The first comprises water pipes, water well casings, metal framework of buildings and other metal embedded in, and in contact with the earth. This group provides a possible means of obtaining a convenient low resistance ground for equipment, facility or system. The second category is commonly referred to as the "ground electrodes" and are composed of buried interconnected ground rods, plates, strips of metal, wires, grids, and counterpoises. The "ground electrodes" provide a means of obtaining the lowest possible resistance contact with the earth. They are installed at, or as near as practical, to the electronic equipment, facility, or system that must be grounded for personnel safety. In addition they must dissipate the electrical charges detrimental to system operational quality and reliability.

a. Water Pipes. The National Electrical Code requires that any watering metering equipment shall be bypassed by a jumper of a size not less than that required for the grounding conductor. The grounding conductor shall bypass the meter and service unions. The water piping system must be made electrically continuous by bonding together all parts which may become disconnected. As with other ground connections, the resistance should be measured before deciding on this type of ground connection. It should be noted that where lead or screw-type joints are used for joining together lengths of pipe they usually provide joints of low resistance. However, if joints are made of "leadite" or similar types of cement, the resistance of these connections may be on the order

of several hundred ohms, rendering the water system useless as a suitable ground connection. Continuous metallic underground water systems generally provide a resistance to ground of less than 3 ohms.

b. Metal Framework. The National Electrical Code states that the metal framework of buildings can be expected to provide resistances to ground substantially below 25 ohms. The value of this resistance depends upon the size of the building, the type of footing, and the subsoil at a particular location. Resistances of several ohms are obtainable and compare favorably with water pipe ground connections. Measurement of resistance is mandatory in determining the suitability of this type of ground connection.

c. Well Casings. Although no specific data is available on the values of resistance of well casing installations, investigation has shown that measurements of less than 2 ohms are obtainable. In some areas, steel pipe employed as casings in wells is used for making ground connections. In any event, well casings located near equipment sites should be considered for their suitability as a ground connection.

d. Driven Electrodes. Driven ground electrodes, more commonly referred to as ground rods or pipes, are used where bedrock is beyond a depth of 10 feet. Ground rods are commercially manufactured in 3/8, 1/2, 5/8, 3/4, and 1 inch diameters. For most applications the 1/2, 5/8, and 3/4 inch diameters in lengths of 8, 10, 12, and 16 feet are normally used. The National Electrical Code specifies that rods of steel or iron be at least 5/8 inch in diameter and rods of nonferrous materials not less than 1/2 inch in diameter. Copper clad steel, one of the most common types of rod, permits driving to a considerable depth without destruction of the rod itself. The copper coat provides direct copper-to-copper connection between the ground conductor and the rod. Galvanized steel rods, copper plated T, H, or channel iron also provide an excellent means of obtaining the lowest possible resistance.

For ease of driving, some rods are available in sections, threaded at both ends. (Figure 7-7). As the sections are driven, the rods are connected by couplings into a continuous conductor. A removable stud will take the driving blows and avoid damage to threads at the joint.

To obtain a specified ground resistance,multiple electrodes may prove of greater practicability than increasing the depth of the grounding rod. Figure 7-8 graphically presents the resistance of multiple driven electrodes at various spacings compared to a single electrode. The direct reciprocal relationship (i.e., the inverse of the number of electrodes is equivalent to the percent reduction in resistance) is not reached in practice because the spacing is limited and the area of influence for each electrode tends to overlap. It should be noted that at 100 feet this reciprocal relationship does equal the inverse proportion. Spacing electrodes at this distance, however, is impractical. The more practical limits for spacing multiple electrodes is usually 10 to 20 feet. At this distance, the optimum reciprocal relationship is approached while practical considerations are satisfied.

The minimum diameter of a driven electrode is limited by mechanical rather than electrical criteria. The usual practice is to select an electrode with a diameter large enough and strong enough to be driven into the soil at a given location. This factor is emphasized in figure 7-9. Curve A is plotted for homogeneous soil. Curves B and C represent the average of hundreds of actual measurements in two different cities. From Curve A, the calculated difference when doubling the diameter of the 1/2 inch rod is a decrease in resistance of only 9.5 percent.

e. Buried Strips, Wire or Cable. Where bedrock is near the surface of the earth or sand is encountered, the soil may be very dry and of high resistivity making it necessary to have an earth connection that extends over a considerable area. Under such conditions the use of buried metal strips, wire, or cables offer the most economical solution. Figure 7-10 illustrates the need for extensive length in this type of installation. Although this is a theoretical curve based on soil of uniform resistivity, actual measurements have been made and are in substantial agreement. From the curve it may seem that if the length is doubled the resistance is approximately halved. This ratio assumes that the strips, wires, or cables are buried in a straight line. If the conductors were curved or coiled, the resistance would tend to be higher because the cross sectional area of the soil would be less. With longer conductors, reactance increases as a factor of the length. Consequently, the use of a number of well spaced, shorted conductors, in parallel, is preferrable to one long conductor. The depth to which such a network

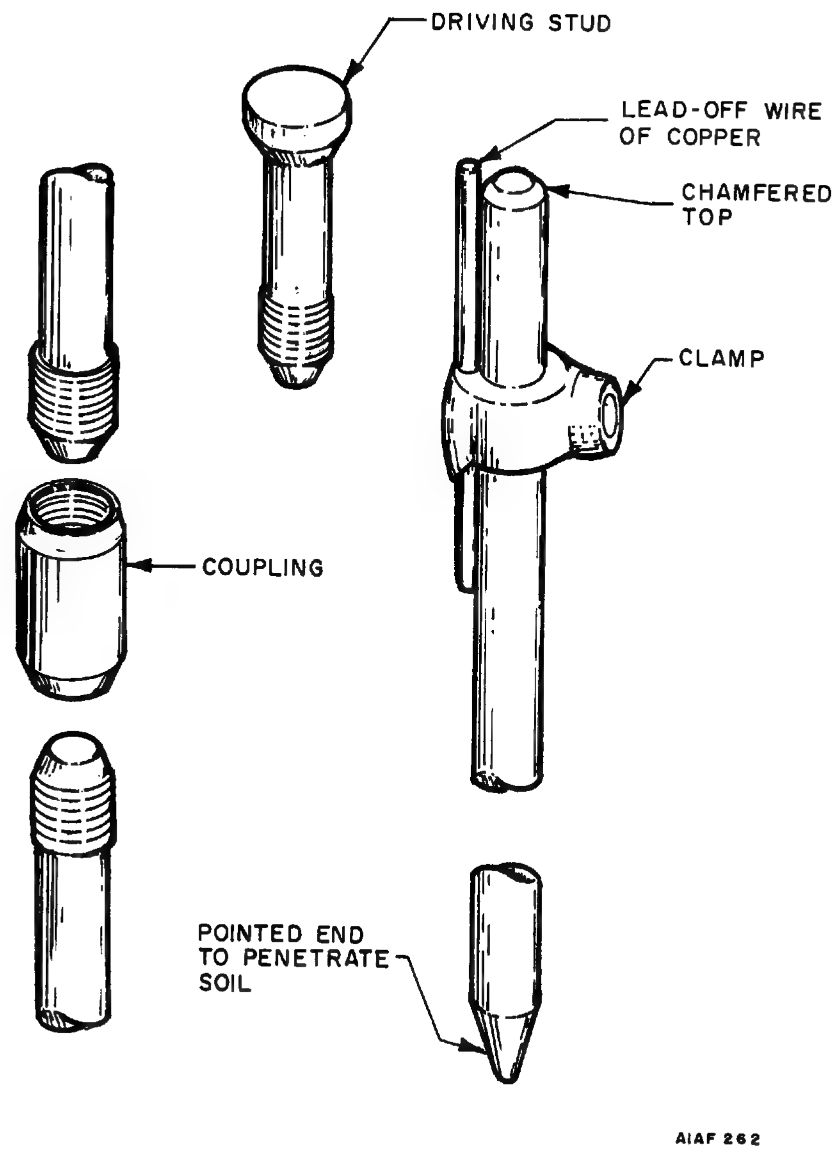


Figure 7-7. Physical Characteristics of Typical Ground Rods

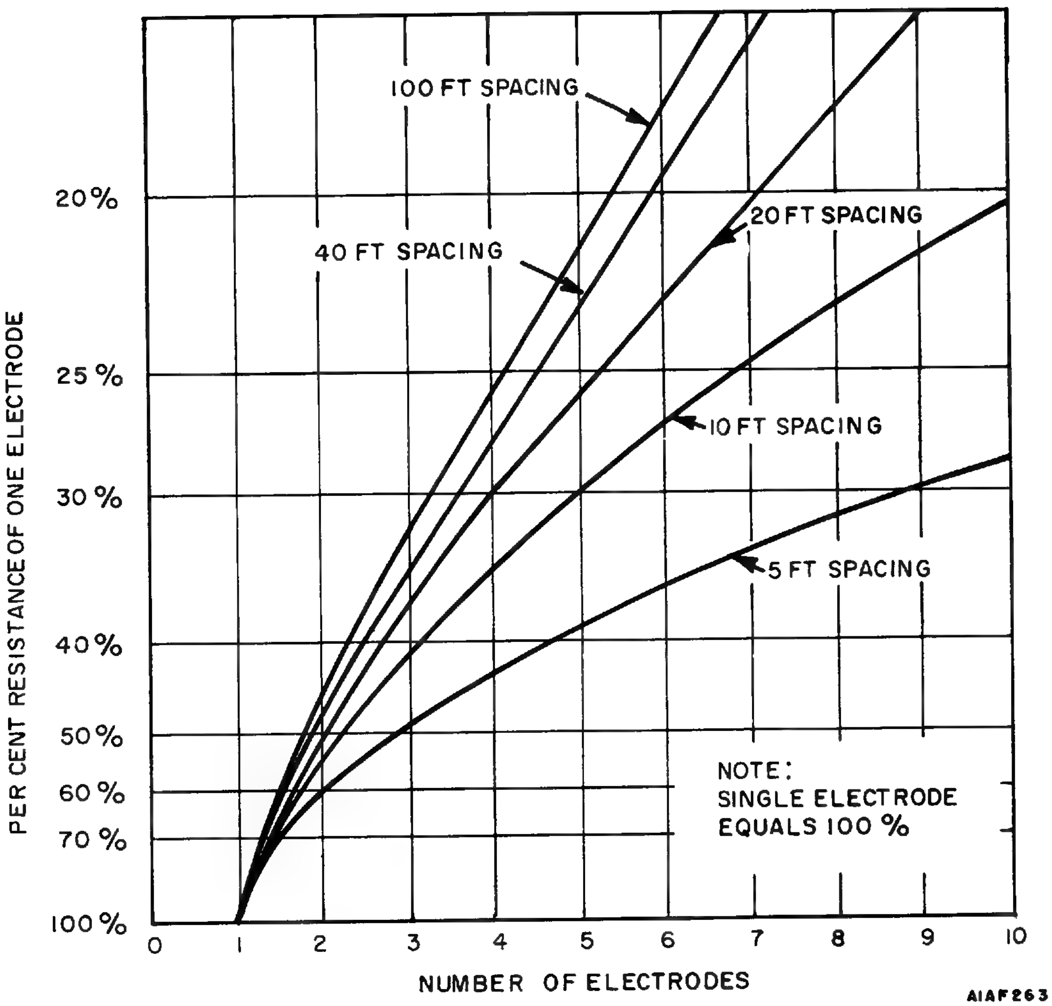


Figure 7-8. Comparative Resistance of Multiple Grounds

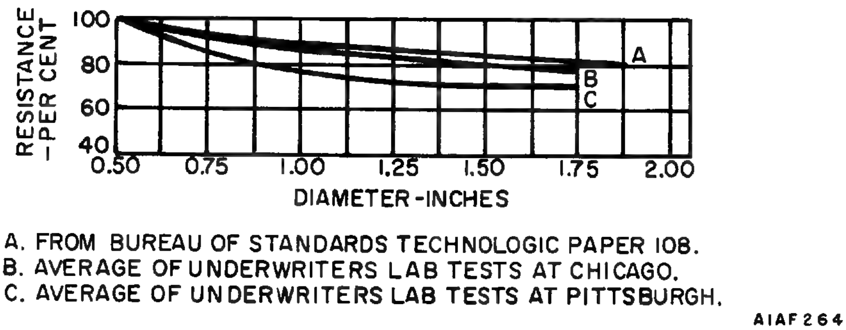


Figure 7 - 9. Effect of Electrode Diameter

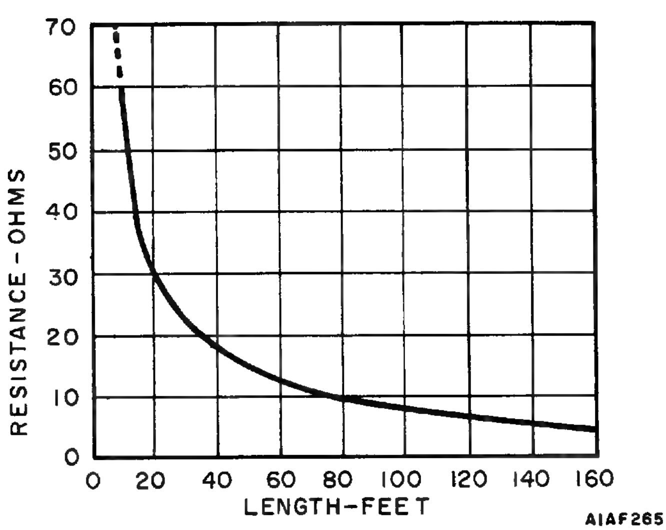


Figure 7 - 10. Resistance as a Factor of Length for Strip Electrode

is buried is not critical. Tests conducted by the Bureau of Standards indicate that a decrease in resistance from the minimum to the maximum practical depth (approximately 18 to 36 inches) is about 5 percent. Similarly, the effect of conductor size is extremely small.

f. Grids. Grid systems usually extend over entire system installations, and may also extend some distance beyond. They consist of conductors buried a minimum of 6 inches in the ground, or stone fill, to form a network of squares. The sizes of the squares will vary with the particular installation, but cable spacings of 10 to 12 feet are commonly used. All cable crossings should be securely bonded and the system connected to the station ground system, as well as all equipment and structural steel work. In rocky ground, where driven electrodes are impractical, it is sometimes more economical and desirable to use a grid system in place of buried strips. In this use, the cables are usually buried at a depth of one or two feet.

To attach ground rods to the ground grid simply to obtain a lower resistance to earth, would not be economically feasible. However, ground rods assist in other ways that make them useful. Under certain climatic changes, the soils resistivity around the grid may increase beyond the stated limit. If ground rods are attached to the grid, contact is with the deeper layer of strata that is probably not affected by such climatic conditions.

g. Buried Plates. The resistance of a plate ground is dependent upon the area of the plate or, more correctly stated, on the overall dimension of the plate. The variation of resistance with respect to area is illustrated in figure 7-11. This curve is calculated for a circular plate in soil having a uniform resistivity. It should be noted that quadrupling the size of the plate approximately halves the resistance. The curve also shows that increasing the area beyond 25 to 30 square feet does not result in an appreciable decrease in resistance. Generally, to facilitate installation, two or more plates connected in parallel are recommended. This same relationship holds for a rectangular plate, although the curve illustrated in the figure should be taken as an indication of relationship and not as a check upon it. The National Electrical Code recommends plate electrodes that present not less than two (2) square feet of surface to earth contact. Ferrous electrodes (iron or steel) should be at least 1/4 inch thick while non-ferrous metals should be a minimum of 0.06 inches in thickness. A burial depth of 5 to 8 feet below grade should be maintained.

h. Counterpoise. The counterpoise is used to reduce the grounding network around a building, tower, or facility in an effort to acquire acceptable ground test readings. Normally it consists of a continuous ring of No. 1/0 AWG bare copper wire bonded to driven electrodes spaced about 20 feet apart installed underground around the perimeter of the building. Grounding conductors from all types of protective systems within the facilities are extended beyond the building foundation and bonded to it. A variation of this is the radial counterpoise which consists of many wires extending radially from a central grounding point (wagon-wheel design) to an outer ring of buried copper. Both counterpoise systems are employed to reduce the impedance of the ground connection, at the same time increasing the capacity coupling between the conductors.

7.3.5 Corrosion and Protection

The choice of electrode metal for ground connections is not important from the standpoint of resistance since almost all the voltage drop is in the surrounding earth. Under ordinary conditions, iron or mild steel is the most economical material. In many areas the effects of corrosion must be considered in the selection of compatible ground electrodes.

a. Factors Effecting Galvanic Corrosion. If large quantities of bare copper wire and plates are buried in the moist soil, good grounds can always be achieved. Such an approach makes a grounding system with excellent properties of conductivity and will last for many years. However, if there are other buried structures - underground pipe, buried cable, steel footings - a penalty is paid for this good ground by the problems that these structures create. If a steel pipe is buried in the earth, it will gradually develop a potential of approximately 0.7 volt negative with respect to a buried bare copper ground cable. If the pipe happens to be galvanized, the potential difference will be 1.1 volt. This difference in potential naturally causes a current to flow from the higher to the lower points. Such current is associated with the galvanic corrosion at the steel pipe, in this case,

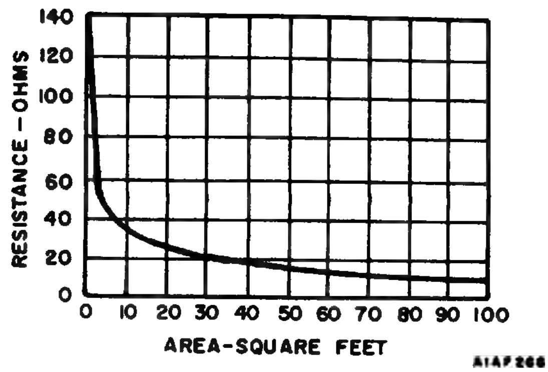


Figure 7 - 11. Resistance as a Factor of Contact Area for Circular Plate

the anodic surface. Effects at the copper ground wire tend to protect it against corrosion, and various salts may be precipitated out of the soil; this reaction is cathodic.

b. Corrosion Preventing Techniques. Corrosive action can be prevented in almost any situation, but the principal limiting factor is the cost. Techniques proven to be the most useful are:

(1) Insulation of Buried Steel. This is the only practical method for such uses as on power transmission lines. A highly satisfactory solution to the cathodic protection problem for new electric cable installations includes the following:

o Use of recognized high resistance coatings on the sheath.

o Insulation of the sheath from external grounds, etc.

o Provision of special heavy-duty and reliable crossbond grounding connections to the sheaths at selected locations.

o Provision of a special generating device (or devices) to provide adequate cathodic protection.

o Provision of special grounding devices that will not appreciably increase or adversely interfere with the cathodic protection scheme.

(2) Replacement of Copper Ground Electrodes. Although copper is the most frequently used material for grounding systems, in many situations other materials can be used to advantage. Such is particularly true in cases where the facilities involved are relatively isolated with respect to other utility and industrial installations. The choice of materials will depend primarily upon soil resistivity and corrosive characteristics at each location. Before the selection of material and consideration of design, sufficient soil and corrosion surveys shall be made

to obtain all data required to support the necessary design decisions.

Adequate and reliable grounding systems have been installed using steel and combinations of steel conductors and zinc electrodes. Because of the difference in conductivity, the cross-sectional area of individual steel conductors must be larger than that for copper. The conductivity ratio of copper to steel is approximately eight to one, and for equal conductivity, the area ratio is approximately the inverse.

In cases where steel is the selected material, solid steel conductors not smaller than one inch diameter are recommended for ground grid meshes, ground rods, and interconnecting conductors. Larger shapes may be required in cases where gradual sacrifice of steel is intentionally planned. Rails salvaged from street railway systems are a typical example of economical, suitable, and sturdy material which has been used successfully for conductors on steel grounding systems. Two promising groups of alloys which may be valuable in the prevention of galvanic corrosion, are the austenitic irons (STDMA-439 Type D-2) and austenitic stainless steel of the 18% chromium and 8% nickel variety. Although these materials are presently in use by some utility companies, much additional research is required to evaluate the effectiveness of such materials for economical use in conjunction with grounding electronic shore facilities.

(3) Sacrificial Anodes for Cathodes Protection. Sacrificial anodes have been successfully employed to provide sufficient potential and current to protect the steel ground rods as well as for building substructures within the environment of the anodes. In addition, grid system resistance has been lowered by the anodes being connected in parallel with the rods. Based on data of previous experiments, the steel ground rods with cathodic protection would last indefinitely and assure adequate ground protection.

The cathodic protected grounding systems described, not only provide the necessary low resistance to earth, but offer cathodic protection to adjacent metallic substructures.

7.3.6 Treating Soil Artificially

Multiple electrodes will not always provide an adequate low resistance to earth. In such instances, it is generally possible to reduce the resistivity of the soil immediately surrounding the electrode by treating the soil with a substance which, when in solution, is highly conductive. There are several substances; however, the better known, in the order of preference are:

Magnesium sulphate ($MgSO_4$) - epsom salts.

Copper sulphate ($CuSO_4$) - blue vitriol.

Calcium chloride ($CaCl_2$).

Sodium chloride ($NaCl$) - common salt.

Potassium nitrate (KNO_3) - saltpeter.

Preference is given to use of magnesium sulphate, which is the most common material used, as it combines low cost with high electrical conductivity and low corrosive effect on a ground electrode or plate. All electrodes used in the soil treatment methods noted above should be of copperweld type.

a. Chemical Treatment. Large reductions in the ground contact resistance of the individual ground electrodes may be expected after chemical treatment of the earth where low resistances are difficult to obtain without chemical treatment. The initial effectiveness of chemical treatment is greatest where the soil is somewhat porous because the solution permeates a considerable volume of earth, and ground contact thereby increases the effectiveness of the electrode. When soil of compact texture in encountered, the chemical treatment is not as

effective at first because the solution tends to remain in its original location for a longer period of time. Chemical treatment limits the seasonal variation of resistance and lowers the freezing point of the surrounding soil. Chemical treatment of the earth around a driven electrode using the magnesium sulphate and water solution is illustrated in figure 7-12 and described as follows:

(1) A 4-foot length (approximately) of 8-inch diameter tile pipe is buried in the ground, surrounding the ground electrode, and filled to within one foot of the ground level with the magnesium sulphate; water thoroughly after installation. The 8-inch tile pipe should have a wooden cover with holes and be located at ground level.

(2) Forty to ninety pounds of chemical will initially be required to retain its effectiveness for two or three years. Each replenishment of chemical will extend its effectiveness for a longer period so that future retreatment occurs less and less frequently.

7.4 BONDING

7.4.1 Basic Considerations

Bonding is essential to the prevention, control, and/or elimination of interference. Inadequate bonding frequently contributes to poor equipment performance; improved bonding almost always results in a reduction of interference. MIL-B-5087 (ASG) and MIL-STD-1310 (NAVY) outline preferred bonding methods.

A bond is an electrical union between two metallic structures used to provide a low-impedance circuit between them. Bonding is the procedure by which the housing or structure of a subassembly or component is electrically connected to another structure, such as the frame of an electrical machine, or chassis of an electronic assembly. Because the reason for bonding two or more units together is to simulate electrically a single homogeneous structure to prevent development of electrical potentials between individual metal structures and non-linear circuits which can produce intermodulation products, it is important that the bond present a low-impedance path to all frequencies of interest capable of causing interference.

The effectiveness of a bond at radio frequencies is neither fully dependent upon nor measureable in terms of its DC electrical resistance; especially at high frequencies, where lengths of bonding jumpers tend to approach the wavelengths of undesirable electromagnetic radiation. When this occurs, a bonding jumper becomes a high-impedance path, and there is a potential drop across the bond causing the metal structures connected by the bond to be at different potentials. As a result, the metal structures do not function effectively as shields and fail to limit interference radiation from and susceptibility to circuits within. Since it is more convenient to measure the DC resistance rather than the AC impedance of a bond, DC measurement is often employed as an indication of low-frequency bonding effectiveness. This should be accomplished with a low resistance bridge. At high frequencies, however, bond effectiveness is best determined by means of impedance measurements because bond capacitance and inductance become significant and may result in relatively high RF bond impedances, despite low DC resistance readings. The equivalent circuit of a bond strap and its impedance as a function of frequency are shown in figure 7-13. In practice, DC resistance measurements are utilized to detect grossly defective bonds, and to determine quickly, by comparison with manufacturer's test data, whether or not bonds on existing equipment have deteriorated in the field. The DC resistance of an adequate bond should be between 0.00025 and 0.0025 ohm. In addition to impairing shielding effectiveness, high-impedance bonding jumpers may re-radiate RF energy. Resonant frequencies of a bonded circuit can be determined by a "Grid-dip Meter," and will roughly indicate the quality of the bond.

In designing and establishing bonding criteria for specific applications, it is necessary to consider a variety of factors, such as interference frequency spectrum and maximum allowable bonding impedances for frequencies within a specific range. Of prime importance are such physical characteristics of the bonds selected as size, strength, fatigue resistance, corrosion resistance, resistivity, and temperature coefficients. It is the design engineer's responsibility to provide bonds that will not deteriorate appreciably even when equipment is subjected

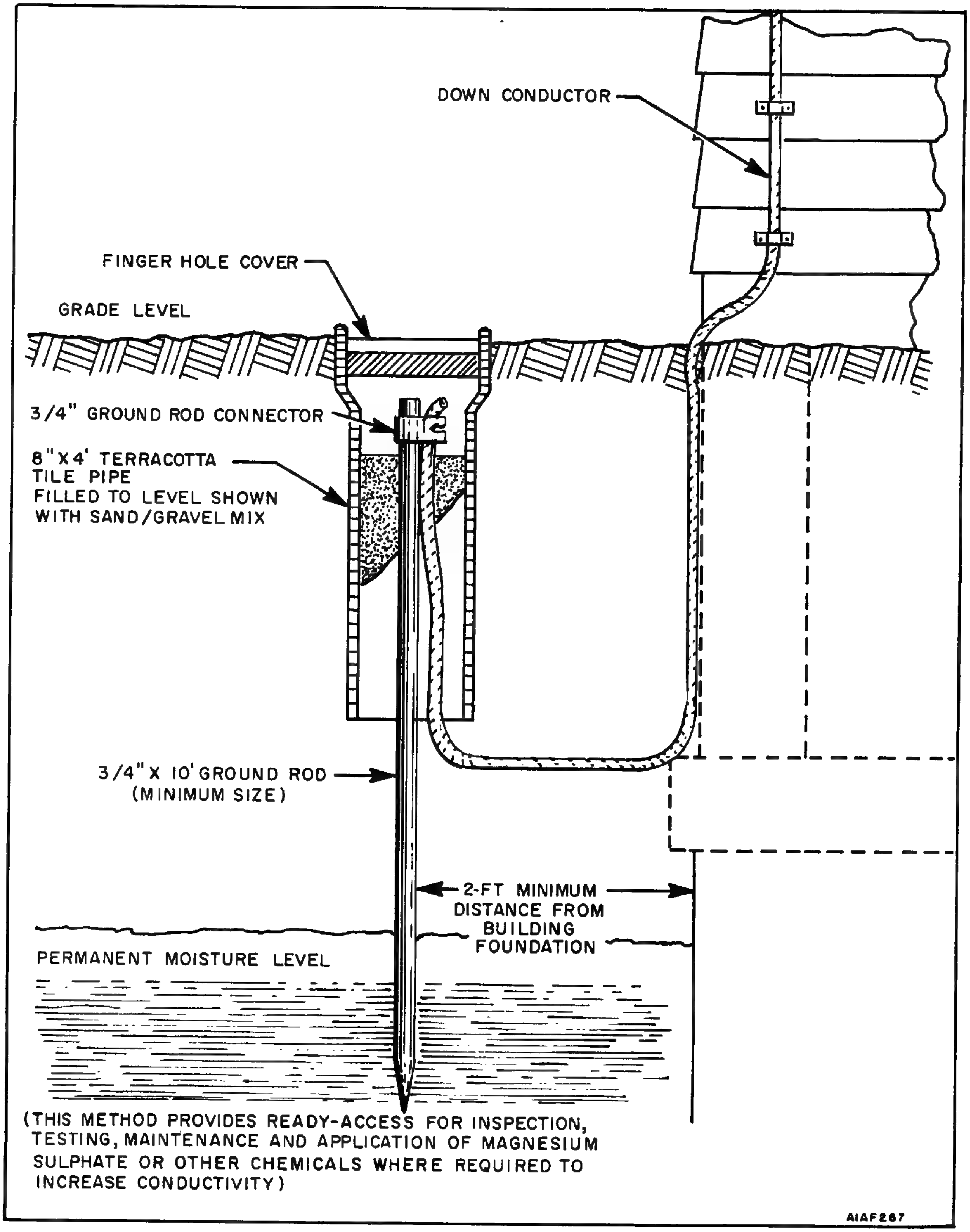


Figure 7 - 12. Typical Ground Rod Installation (Chemically Treated)

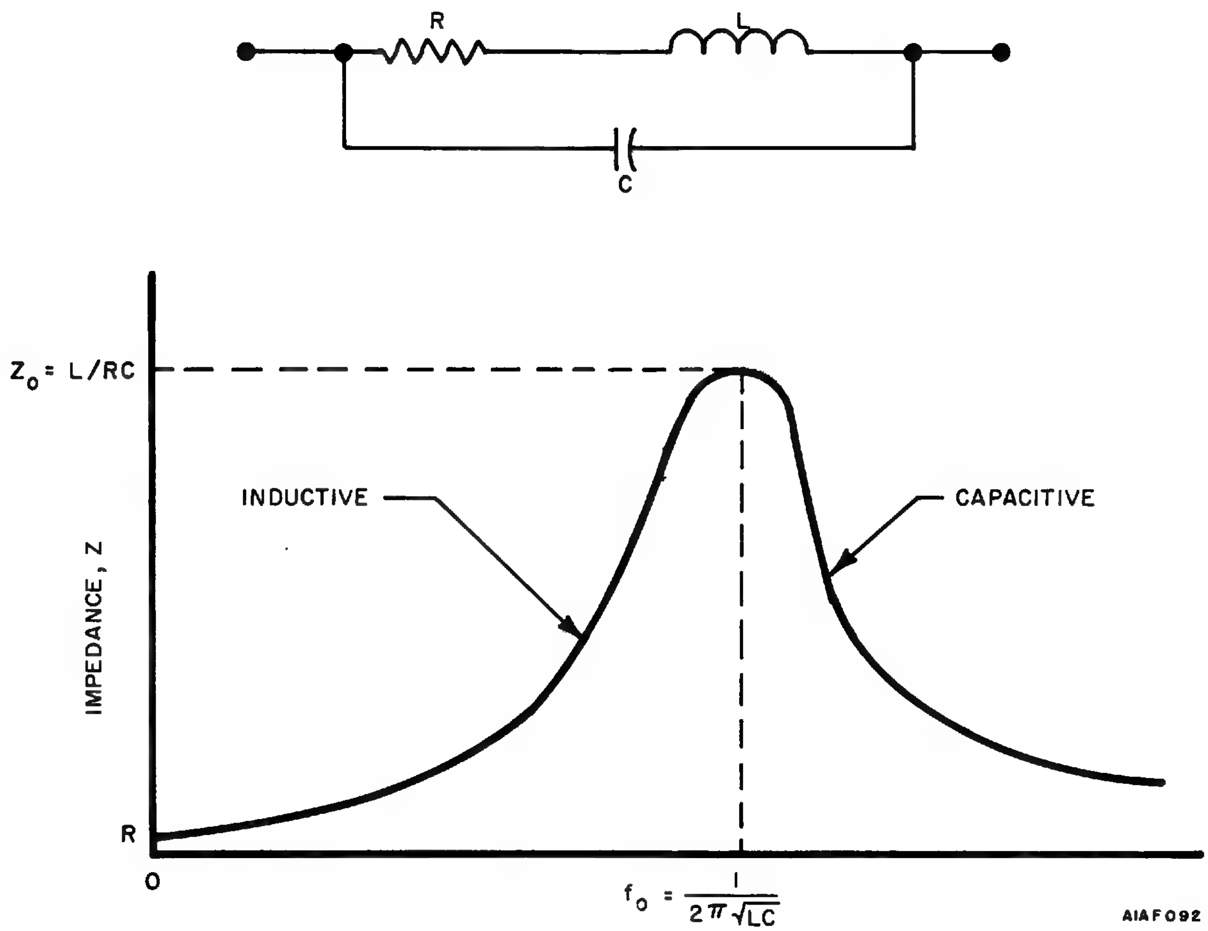


Figure 7 - 13. Bonding Strap Impedance Characteristics

to adverse environmental conditions. Bonds may be affected by electrolytic action between the metals used and their surroundings. An excellent bond at time of fabrication may actually become a serious interference source shortly afterwards if proper precautions described herein have not been taken.

Bonding jumpers should preferably be flat, thin, and short solid straps to provide large surface areas for low RF impedance (RF currents flow along conductor surfaces). The measured RF impedance of a typical flat bond strap at frequencies up to 30 MHz increases almost linearly with frequency; such impedance is due almost entirely to the self-inductance of the strap. The capacitance between the bonded members is in parallel with the inductance of the bond strap; and the bond strap has the characteristics of a parallel capacitance-inductance circuit operating far below its resonant frequency. At the frequency of self-resonance, the RF impedance of such a parallel capacitance-inductance circuit is very high compared to its DC resistance, and effectiveness of the bond strap is nil.

7.4.2 Types of Bonds

There are two classifications of bonds: direct and indirect. The most desirable of these is the direct bond. This term is applied to permanent, metal-to-metal joints such as are provided by welding or brazing. Indirect bonds, or flexible metal straps, are used when metals to be bonded cannot be placed in direct contact; for example, when there is a need for motion between bonded members.

a. Direct Bonds. Direct bonds include permanent metal-to-metal joints formed of machined metal surfaces; or with conductive gaskets held together by lock-threaded devices, riveted joints, tie rods, or pinned fittings driven tight and not subject to wear or vibration. The best bonded joint is formed by welding, brazing, or sweating. Soldering is not a good method of direct bonding because soldered joints have appreciable contact resistance. Basic requirements for direct bonding are that good metal-to-metal contact be provided for the life of the joint, and that precautions be taken to seal the joint against moisture that would cause galvanic corrosion. Dissimilar metals in direct contact should be avoided. Screw threads are never considered adequate bonding surfaces. In particular, sheet-metal type screws are inadequate for use in bonding. If two structural members are held together by screws, the impedance between them is usually comparatively high unless very low ohmic contact is maintained.

b. Indirect Bonds. When a direct bond is not practical, the designer should select an indirect bond. A good indirect bond is one that presents a low impedance throughout the interference spectrum and retains its usefulness for an extended period of time. An indirect bond is usually a bond strap or jumper, mechanically held by means of bolts, rivets, welding, brazing, or sweating. Tooth-type lockwashers are used with bolt fasteners to ensure no deterioration of the metal-to-metal contact of bond strap connections. The most significant feature of a bond strap is its resiliency. When a solid strap is used, resiliency is determined by its material and thickness. Beryllium copper or phosphor bronze are often used and, under conditions of severe vibration, a corrugated strap often proves useful in preventing excessive damping and in achieving maximum service life. Figure 7-14 shows a typical bond strap bolted into position. Good metal-to-metal contact at the point of bonding is required for efficient operation, and any discussion of corrosion is not intended to compromise this requirement.

o Bonding Jumpers. Bonding jumpers are short, round, braid conductors for application where the interfering signal frequency is below a few megahertz. They are generally used in low-frequency devices, and where the development of static charges must be prevented.

o Bond Straps. Bond straps are either solid, flat, metallic conductors, or a woven braid configuration where many conductors are effectively in parallel. Solid metal straps are generally preferred for the majority of applications.

Braided or stranded bond straps are not generally recommended because of several undesirable characteristics. Oxides may form on each strand of non-protected wire and cause corrosion. Because such corrosion is not uniform, the cross-sectional area of each strand of wire will vary throughout its length. The nonuniform

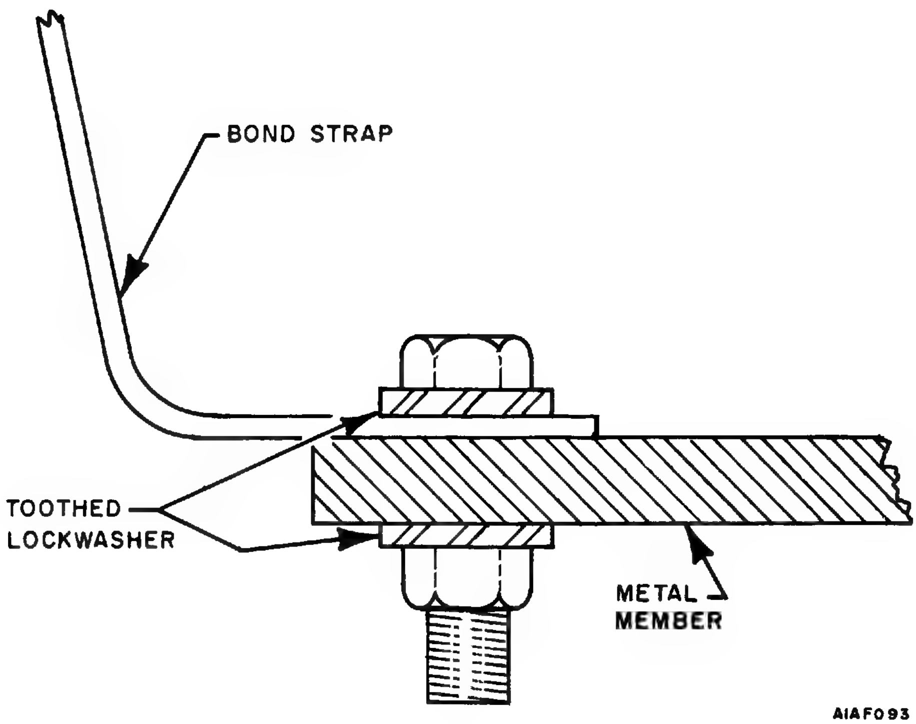


Figure 7 - 14. Recommended Bond Strap Bolting Installation

cross-sectional areas (and possible broken strands of wire) may lead to generation of unwanted signals within the cable or strap. Broken strands may act as efficient antennas at high frequencies, and emissions may be generated by intermittent contact between strands. In some cases solid straps may be preferrable because of lower self-inductance. The direct influence of bond strap construction on RF impedance is shown on the graph of figure 7-15, where the impedances of two bonding straps and of No. 12 wire are plotted against frequency. The relatively high impedance at high frequencies illustrates that there is no adequate substitute for direct metal-to-metal contact. A rule of thumb for achieving minimum bond strap inductance is that the length-to-width ratio of the strap should be 5:1 or less. This ratio determines the inductance, the major factor in the high-frequency impedance of the strap.

c. Bonding Metal Selection and Bond Strap Finishes

The choice of material for a given bonding application is usually dictated by consideration of the metals being bonded and the environment within which the bond must exist. In bonding, the necessity for joining dissimilar metals is frequently unavoidable. In such cases, galvanic corrosion becomes an important consideration. Factors contributing to galvanic corrosion are the relative closeness of metals in the electromotive series and the amount of moisture present.

Several methods can be employed for minimizing or preventing corrosion and its adverse effects on bonding. One is to use metals low on the activity table, such as copper, lead or tin (table 7-4). Where members of the electrolytic couple are widely separated on the activity table, it is sometimes practical to use a plating such as cadmium or zinc, which helps to reconcile the dissimilarity. Thin, bimetallic plates, formed by mechanical bonding of dissimilar metals cold flowed together under high pressures, have been used to interconnect two structural units of dissimilar metals. Where bimetallic plates are to be used, the junctures of the two metals are normally covered with a protective coating, such as grease or polysulphate, to exclude moisture and retard corrosion. This coating reduces the area of metal exposed to an electrolyte, thus reducing corrosion. If bonding is such that corrosion is likely to occur, the bond should be designed as a replaceable element, such as a jumper, plate, separator, or washer.

Acceptable contact surface materials that may be used to fasten bonding jumpers to structures are indicated in table 7-5. Typical methods for fastening connection jumpers to the various case metal types are illustrated in figure 7-16. The arrangement of the metals listed in this table is in the order of their decreasing galvanic activity when exposed to an electrolyte. The screws, nuts, and washers to be used in making the connections are indicated as Type I, cadmium or zinc plated, or aluminum, and Type II, passivated stainless steel. Where neither type of securing hardware is indicated, Type II is preferred from a corrosion standpoint.

The possibility of galvanic and/or electrolytic action necessitates extreme care in assembling joints that serve as bonds. Surfaces should be absolutely dry before mating, and should be held together under high pressure to minimize the possibility of moisture entering joints. The use of number 7/0 garnet finishing paper or equivalent is recommended to remove paints, anodic films, and oxides from surfaces. Care must be taken not to remove excessive metal under the protective finish. Abrasives, such as emery cloth or sandpaper, cause corrosive action because their particles embed themselves in the metal and should not be used. The contact area should be wire brushed clean and should be about 1-1/2 times greater than the area necessary for actual mounting. After a joint (free of moisture) is assembled, the periphery of the exposed edge should be sealed with suitable grease or a polysulphate coating. See figure 7-14.

7.4.3 Bonding Applications

a. Shock Mounts. A frequent application for which indirect bonding is the only suitable type is that involving shock mounted equipment. The designer should consider the degree of relative motion to be expected between two surfaces to be bonded, the characteristics of the materials involved, and the frequency range over which the bonding is expected to be effective. A typical shock mount is shown on figure 7-17. The application of a bond strap to a vehicle engine is shown on figure 7-18.

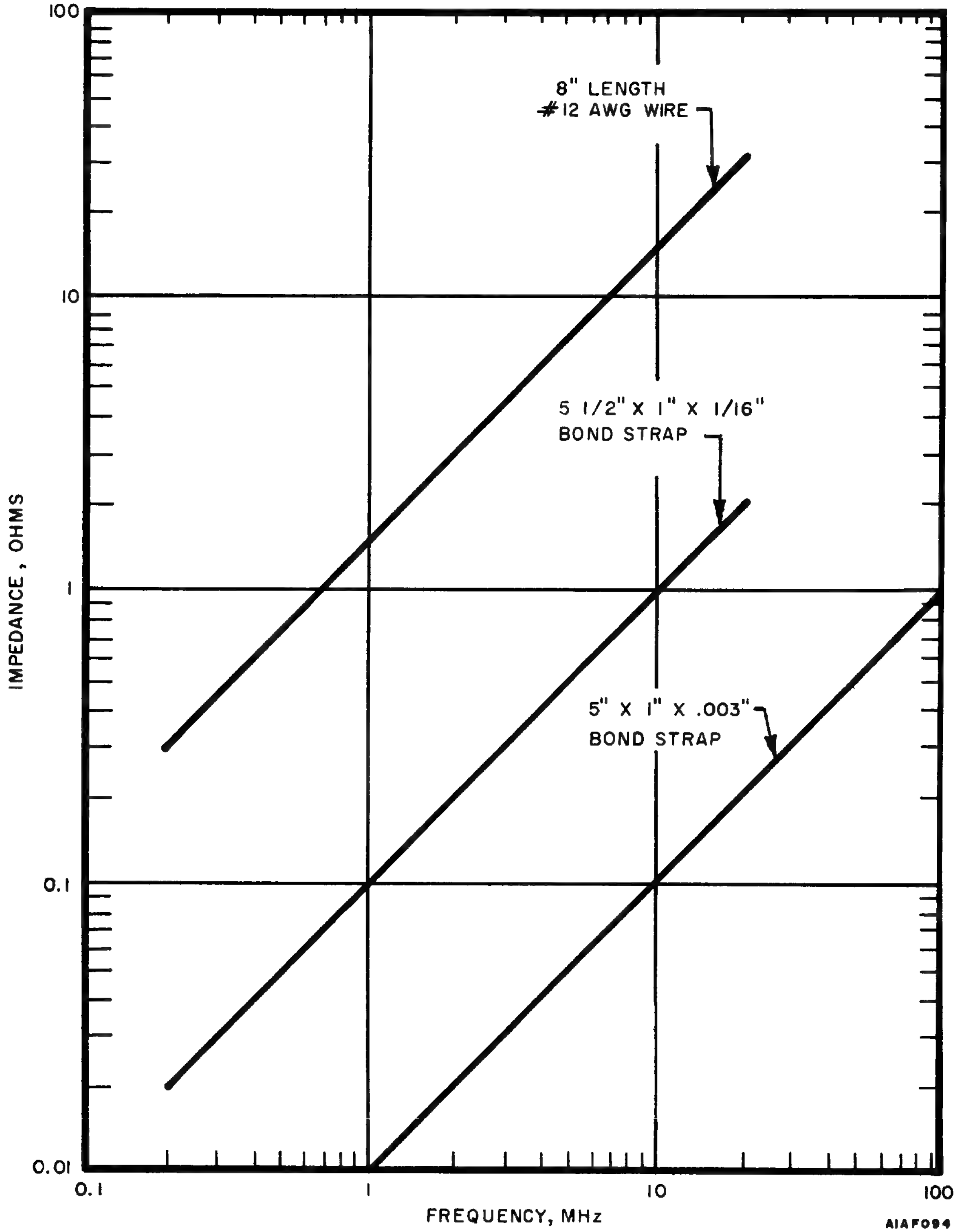


Figure 7 - 15. Impedances of Bond Straps and No. 12 AWG Wire

Table 7-4. Electromotive Force Series of Commonly Used Metals*

METAL	ELECTRODE POTENTIAL VOLTS
Magnesium	+2.40
Aluminum	+1.70
Zinc	+0.762
Chromium	+0.557
Iron	+.0441
Cadmium	+0.401
Nickel	+0.231
Tin	+0.136
Lead	+0.122
Copper	-0.344
Silver	-0.798
Platinum	-0.863
Gold	-1.50

* Select dissimilar metals so that if corrosion occurs, it will be in the replaceable components, such as grounding jumpers, washers, bolts or clamps, rather than structural members or equipment enclosures. When two different metals are in contact, the one higher in the electromotive-force series will be more affected by corrosion than the other. The smaller mass (generally the more easily replaceable) should therefore be made of the higher metal; for example cadmium-plated washers are recommended for use with steel surfaces.

Table 7-5. Metal Connections

METAL STRUCTURE (OUTER FINISH METAL)	CONNECTION FOR ALUMINUM JUMPER	SCREW TYPE[a]	CONNECTION FOR TINNED COPPER JUMPER	SCREW TYPE[a]
Magnesium and magnesium alloys	Direct or magnesium washer	Type I	Aluminum or magnesium washer	Type I
Zinc, cadmium, aluminum and aluminum alloys	Direct	Type I	Aluminum washer	Type I
Steel (except stainless steel)	Direct	Type I	Direct	Type I
Tin, lead, and tin-lead solders	Direct	Type I	Direct	Type I or II
Copper and copper alloys	Tinned or cadmium-plated washer	Type I or II	Direct	Type I or II
Nickel and nickel alloys	Tinned or cadmium-plated washer	Type I or II	Direct	Type I or II
Stainless steel	Tinned or cadmium-plated washer	Type I or II	Direct	Type I or II
Silver, gold, and precious metals	Tinned or cadmium-plated washer	Type I or II	Direct	Type I or II

a - Type I is cadmium or zinc-plated, or alumium; Type II is stainless steel. Where either type is indicated as acceptable, type II is preferred from a corrosion standpoint.

The resiliency of the bonded mount should be determined by characteristics of the mount, not of the bond strap. The strap should not significantly dampen the shock mount, and where necessary, it should be corrugated to withstand severe and continued vibration. Where interference suppression is desired in the VHF range and higher, two bond straps across each shock mount should be used. This arrangement reduces the inductance of the bond to half of its former inductance and increases the resonant frequency of the strap. The use of tooth-type lock washers is preferable so that perforation of any nonconductive coating (with improved electrical contact) is assured. Where severe environments are involved, joints should be protected after tightening with a suitable grease or polysulphate coating to preclude corrosion at contact surfaces.

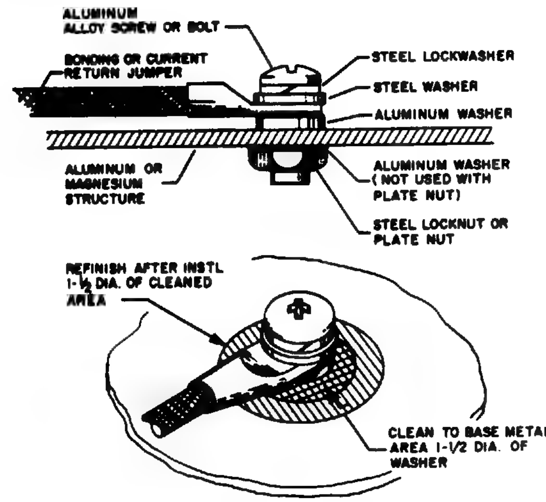
b. Rotating Joints. It is often necessary to bond shafts of rotating machinery to prevent accumulation of static charges. Bonding is generally accomplished by use of a slip ring and brush assembly, or a phosphor-bronze finger riding directly on the shaft.

BOLT SIZE:

BONDING – NO. 6 & NO. 8 SCREW WHERE EDGE DISTANCE WILL NOT PERMIT NO. 10
– 3/16-INCH DIA. MIN WHERE POSSIBLE

100-AMP RETURN-1/4-INCH DIA. MIN
200-AMP RETURN-3/8-INCH DIA. MIN

NOTE: Electrical bonding to magnesium structure for current return is prohibited

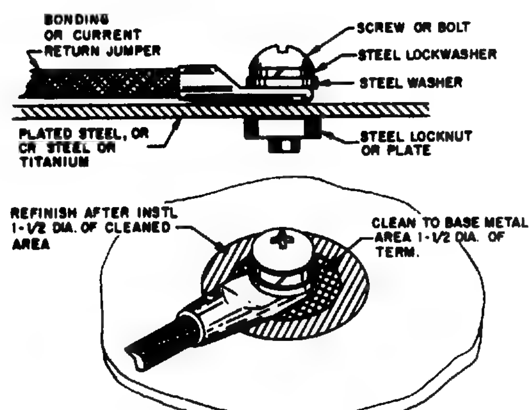


a. BOLTED TO ALUMINUM OR MAGNESIUM ALLOY STRUCTURE

BOLT SIZES:

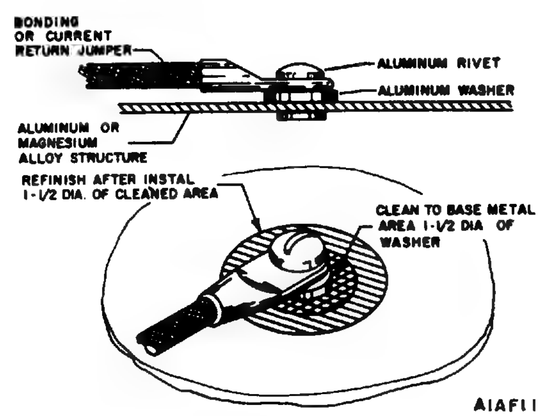
BONDING – NO. 6 & NO. 8 SCREW WHERE EDGE DISTANCE WILL NOT PERMIT NO. 10 SCREW
– 3/16 - INCH DIA. MIN WHERE POSSIBLE

100-AMP CURRENT RETURN-1/4-INCH DIA. MIN
200-AMP CURRENT RETURN-3/8-INCH DIA. MIN



b. BOLTED TO ALLOY STEEL, PLATED STEEL OR TITANIUM

NOTES:
1. Not applicable to bonding jumpers used for current return
2. Use bolted connections where jumper is used for current return
3. Ensure that rivet size is equal to the equivalent bolt size



c. RIVETED TO ALUMINUM OR MAGNESIUM ALLOY

Figure 7 - 16. Connection Jumpers

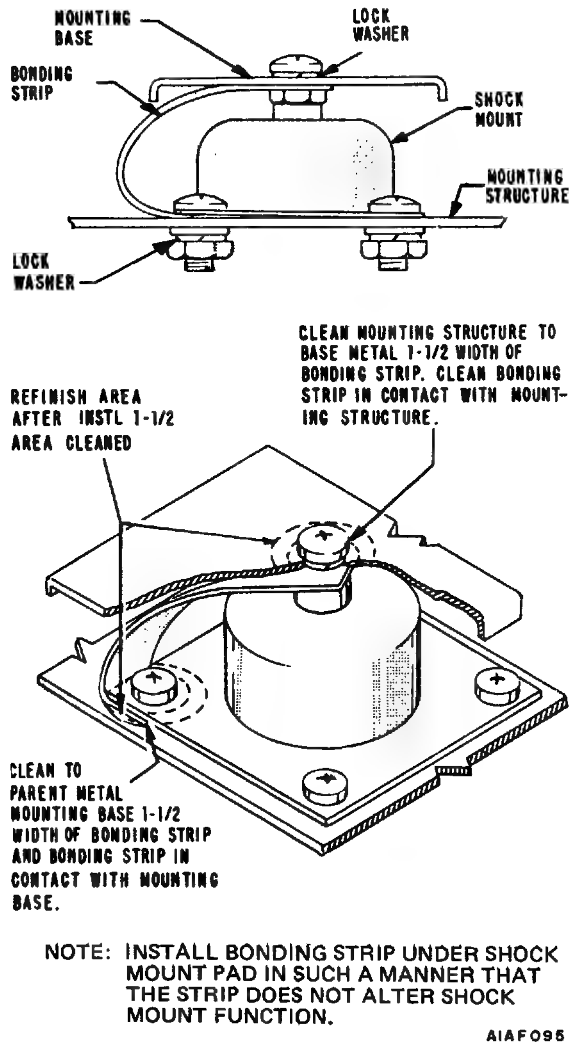


Figure 7 - 17. Typical Shock Mount Bond

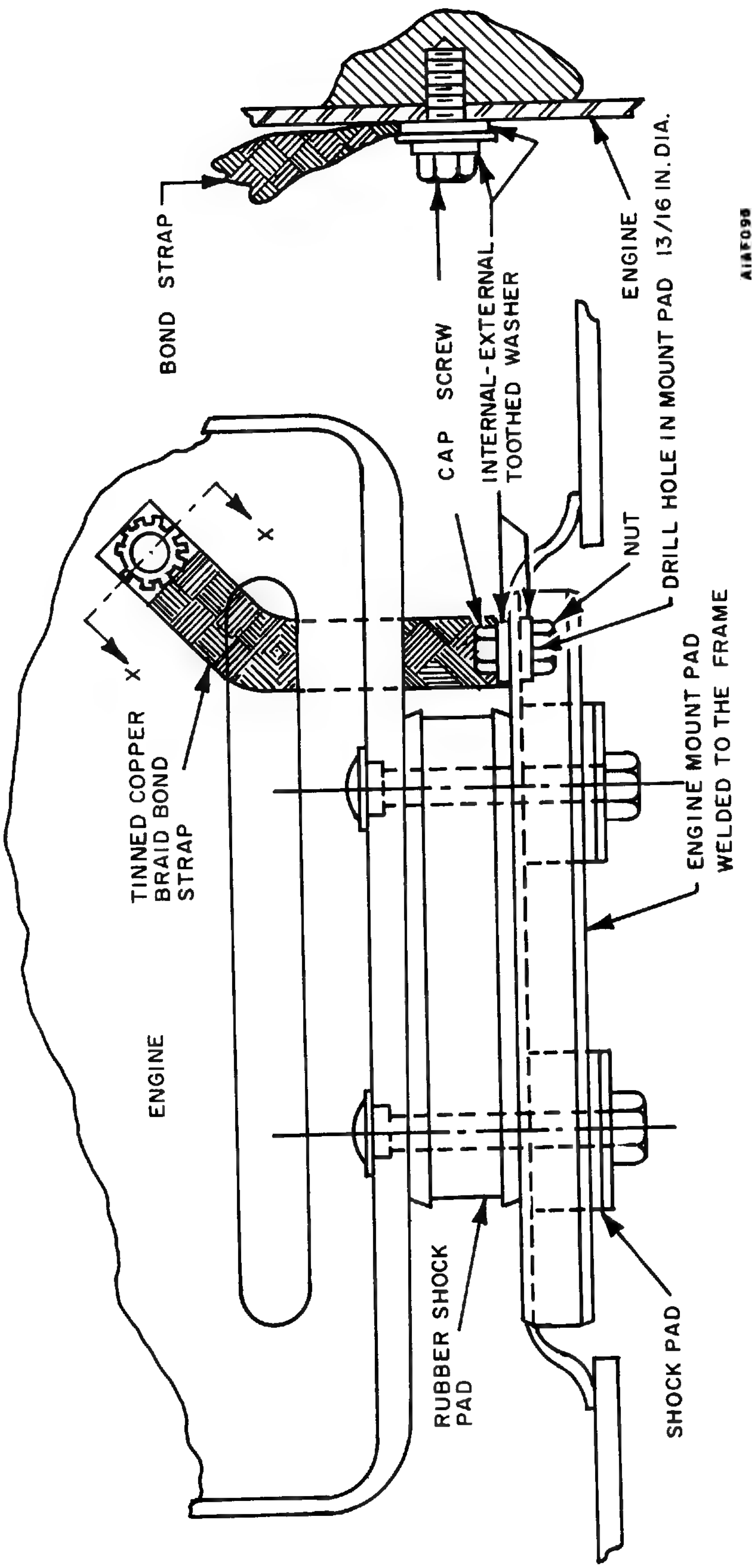


Figure 7 - 18. Bonded Engine Shock Mount-Front

c. Tubing Conduit. The outer surfaces of long spans of conduit or shielded cable may be high-impedance paths for interference currents from external sources. To minimize this possibility, such spans should be properly bonded to structures at both ends and at several intermediate points. Ordinary clamps cannot be used to bond flexible conduit since the required pressure on a comparatively small surface area of the conduit may be sufficiently high to compress or collapse it. To overcome this, a flared split-sleeve is fitted around the flexible conduit. This sleeve distributes the high pressure of the bonding clamp over a large area, thereby exerting low pressure on the conduit (figure 7-19). Figure 7-19 illustrates a method for bonding rigid conduit to a structure through supporting attachments. The conduit or tubing, to which bonding clamps are attached, should be cleansed of paint and foreign material over the entire area covered by the clamps. All insulating finishes should be removed from the contact area before assembly, and anodized screws, nuts, and washers should not be used to attach contacting parts. If, in bolting the clamp to the bonding surface, a tooth-type washer is used, protective coatings, unless very thick or tough, need not be removed from the surface because the points of the washer will penetrate to the bare metal.

d. Hinges. Hinges do not provide a path for electrical conductivity; or an RF shield. Where hinges must be used, it is necessary to accomplish bonding by other means. Figure 7-20 shows a typical configuration for bonding hinges. Flexible bonding straps, made of thin metal, are separated along the hinges by not more than 2 inches.

e. Cable Trays. Cable trays should be utilized as part of the overall system bonding scheme. Each section of each tray should be bonded to the following section to provide a continuous path (figure 7-21). The trays should also be connected to equipment housings by wide, flexible, solid bond straps. Such connections reduce the level of interference propagated into the equipment, thus precluding any difference of potential between equipment housings. A typical example of cable tray bonding is shown on figure 7-22.

f. Rack Bonding. The equipment rack provides a convenient means of maintaining electrical continuity between such items as rack-mounted chassis, panels and the ground plane. It also serves as an electrical intertie for the cable trays. A typical equipment cabinet, with the necessary modifications to provide such bonding, is shown on figure 7-23. Bonding between the equipment chassis and the rack is achieved through the equipment front panel and the rack right-angle bracket. This bracket is grounded to the unistrut horizontal slide that is welded to the rack frame. The lower surfaces of the rack are treated with a conductive protective finish to facilitate bonding to the ground plane mat. The ground stud at the top of the rack is used to bond the cable tray to the rack structure, which is of welded construction. Figure 7-24 illustrates a typical bonding installation. The cable tray is bonded to the cable chute; the cable chute is bonded to the top of the cabinet; the cabinet is bonded to the flush-mounted grounding insert (which is welded to the ground grid); and the front panel of the equipment is bonded to the rack or cabinet front panel mounting surface. Nonconductive finishes are removed from the equipment front panel before bonding. The joint between equipment and cabinet may have to serve a dual purpose: that of achieving a bond and that of preventing interference leakage from the cabinet if the joint is designed to provide shielding. If such shielding is a requirement, conductive gaskets should be used around the joint to ensure that the required metal-to-metal contact is obtained. If the equipment is in a shock-mounted tray, the tray should be bonded across its shock mounts to the rack structure. Connector mounting plates should use conductive gasketing to improve the chassis bonding. If chassis removal from the rack structure is required, a one-inch-wide braid with a vinyl sleeving should be used to bond the back of the chassis to the rack. The braid should be long enough to permit withdrawal of the chassis from the rack.

g. Other applications are illustrated in figures 7-25 through 7-33.

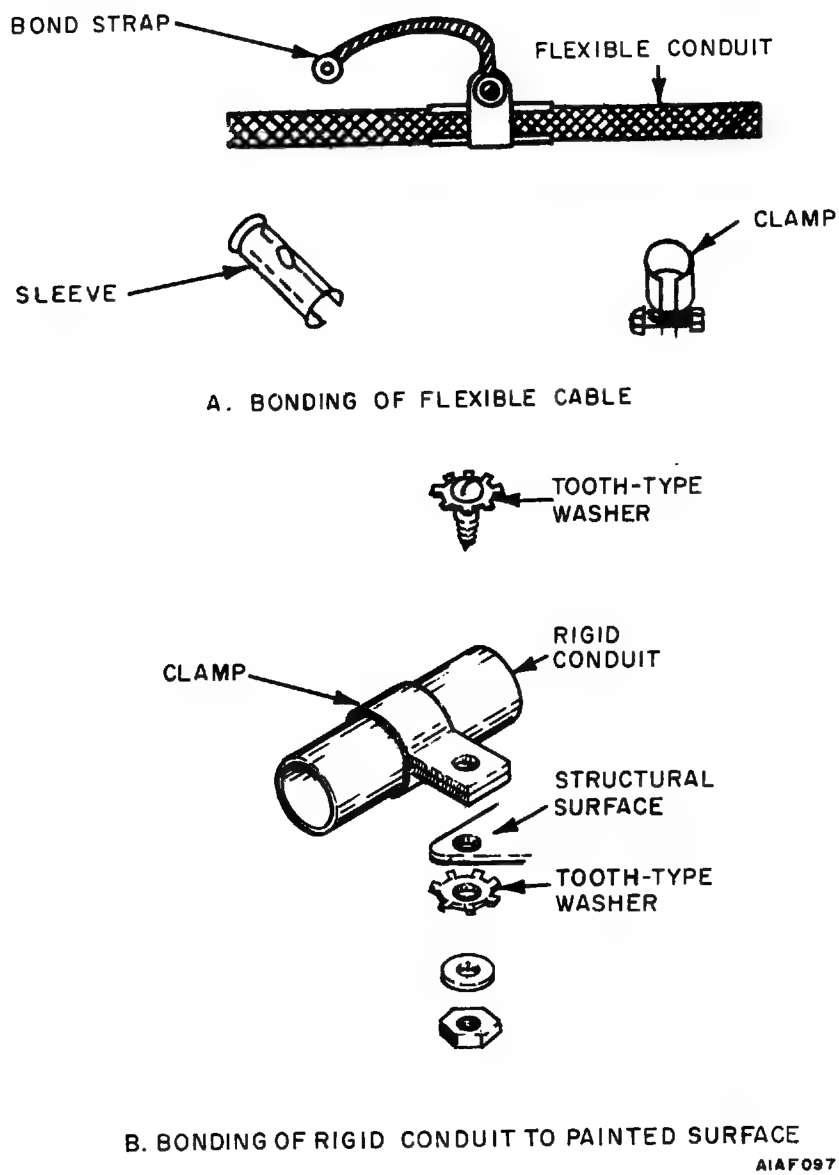


Figure 7-19. Cable and Conduit Bonding

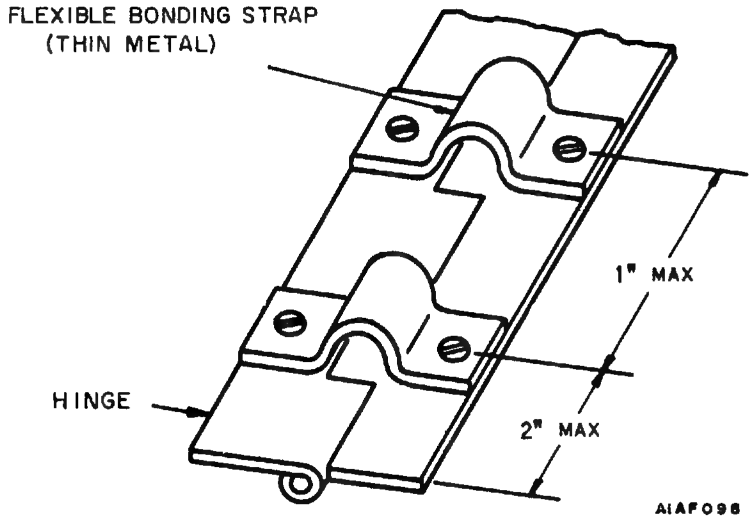


Figure 7 - 20. Bonding of Hinges

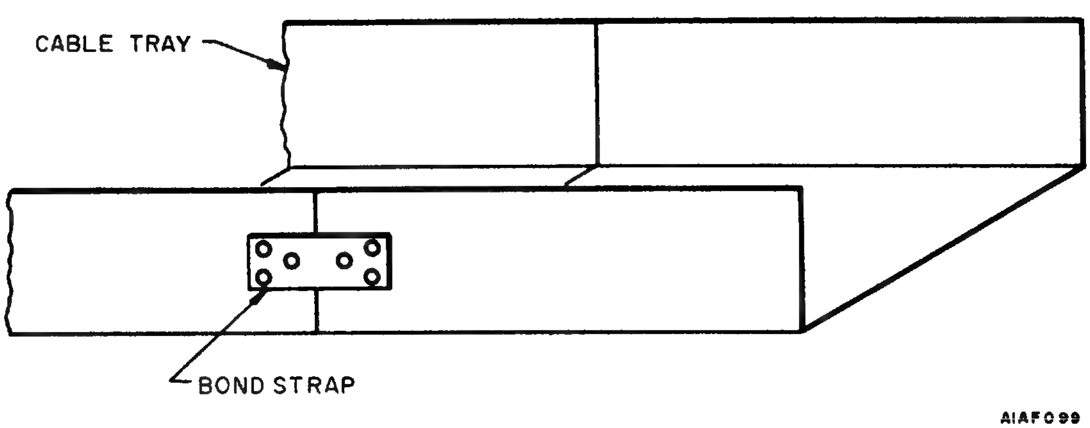


Figure 7 - 21. Cable Tray Section Bonding

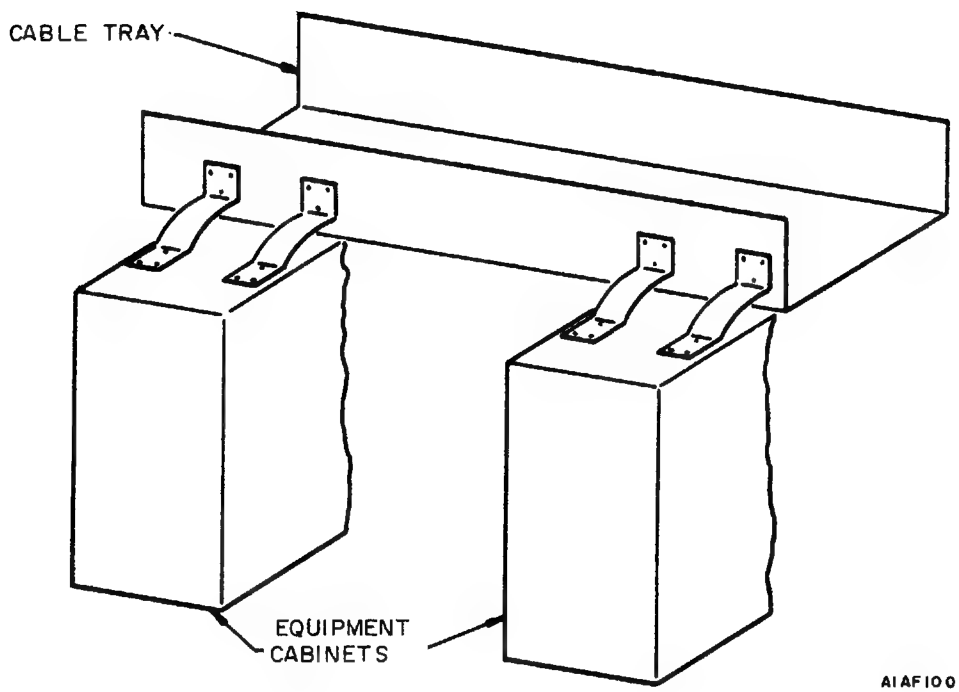


Figure 7 - 22. Equipment Cabinets Bonded to Cable Tray

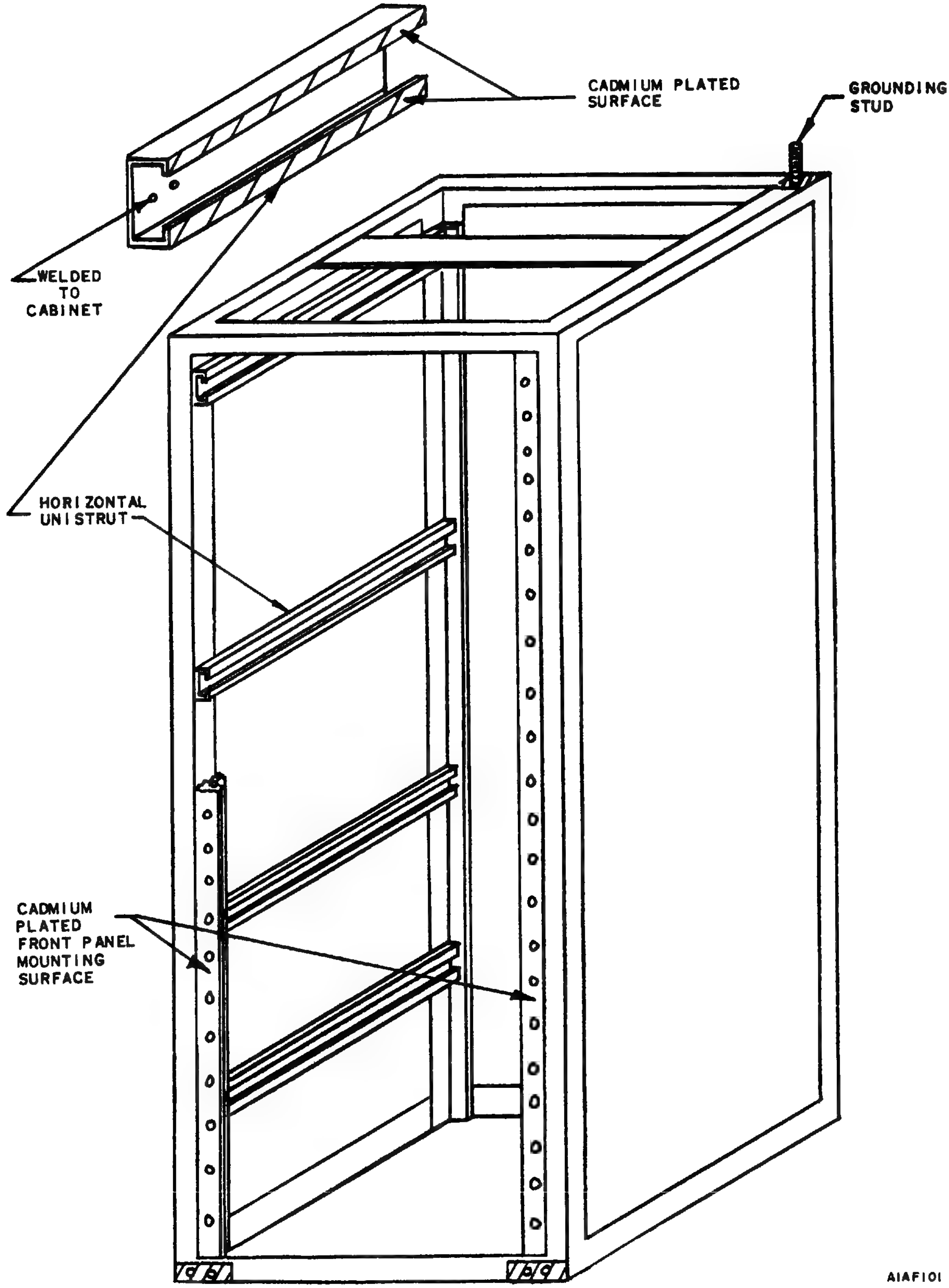


Figure 7 - 23. Cabinet Bonding Modifications

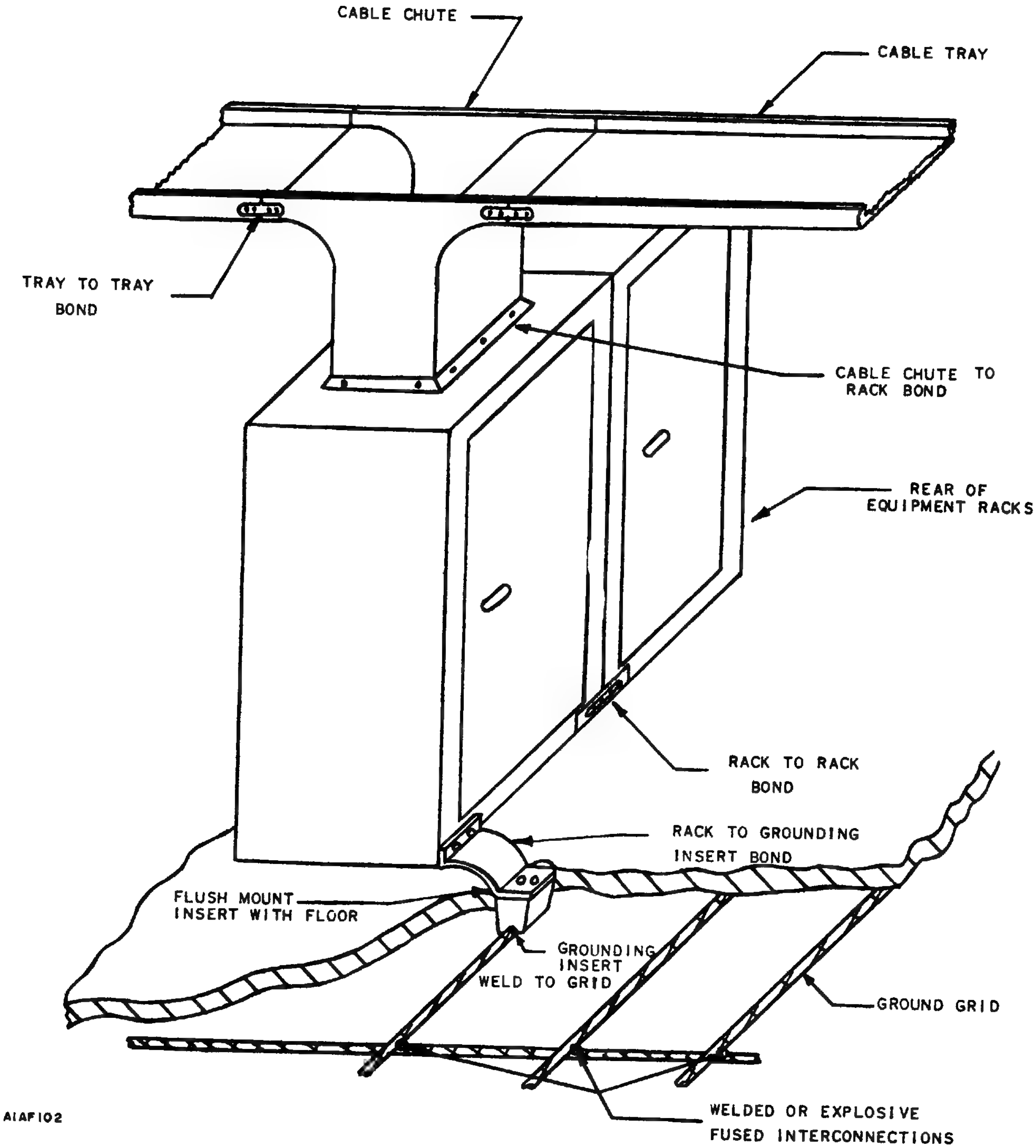


Figure 7 - 24. Typical Cabinet Bonding Arrangements

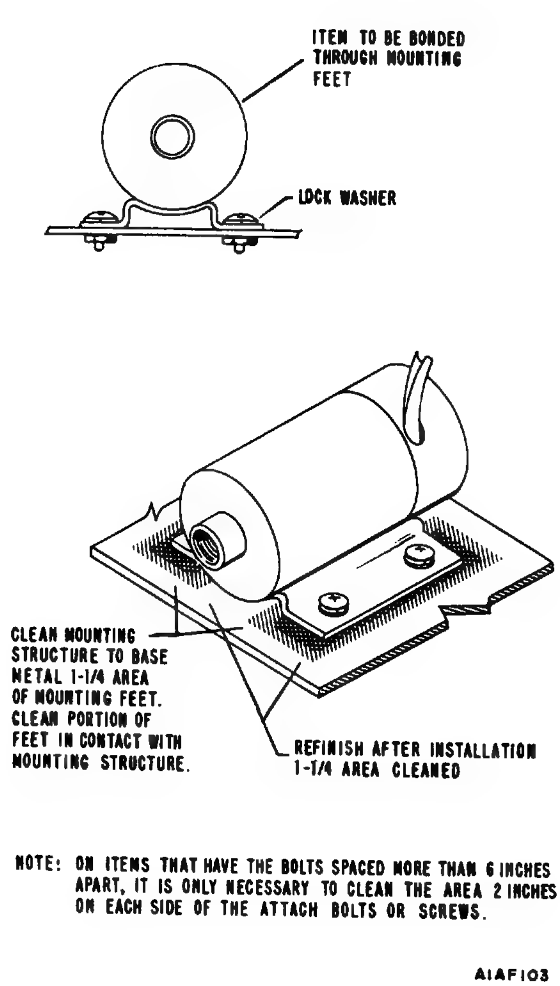


Figure 7 - 25. Typical Bonding of Equipment Installed on Structure with Mounting Feet

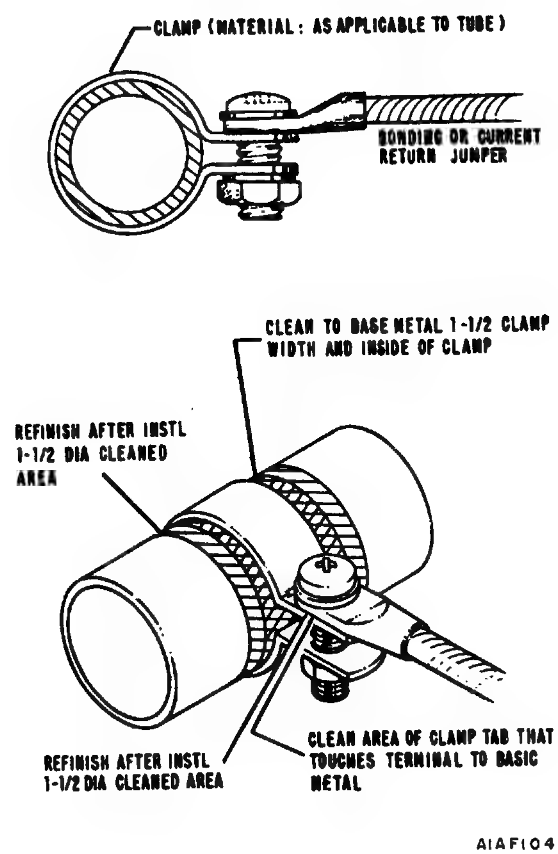


Figure 7 - 26. Clamp Connection - Jumper to Tube

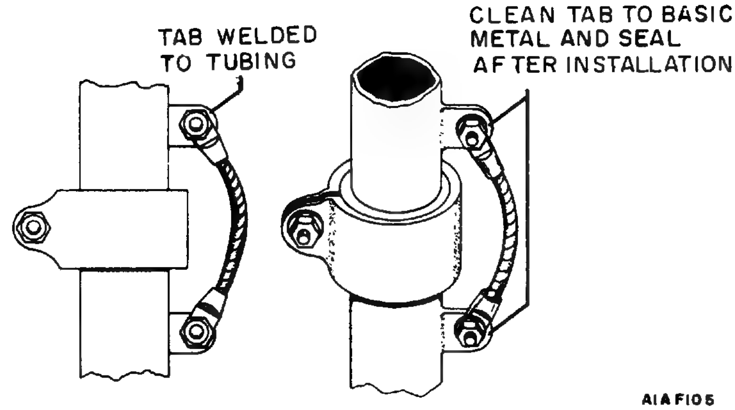


Figure 7 - 27. Typical Method of Bonding Tubing Across Clamps

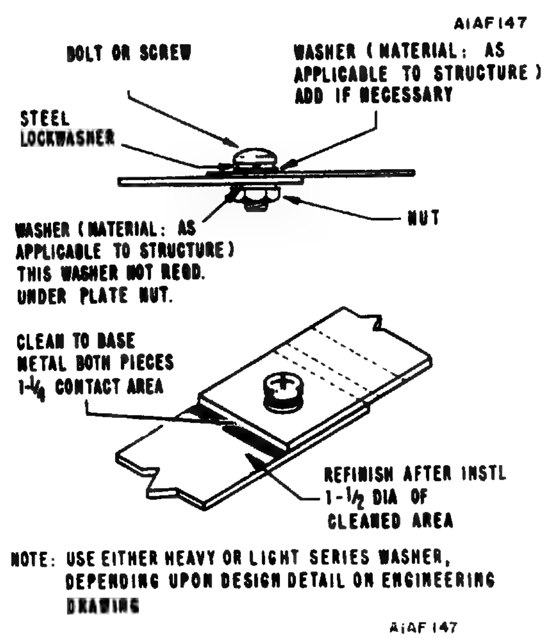


Figure 7 - 28. Preparation of Bonding Connection
in Bolted Structural Joints

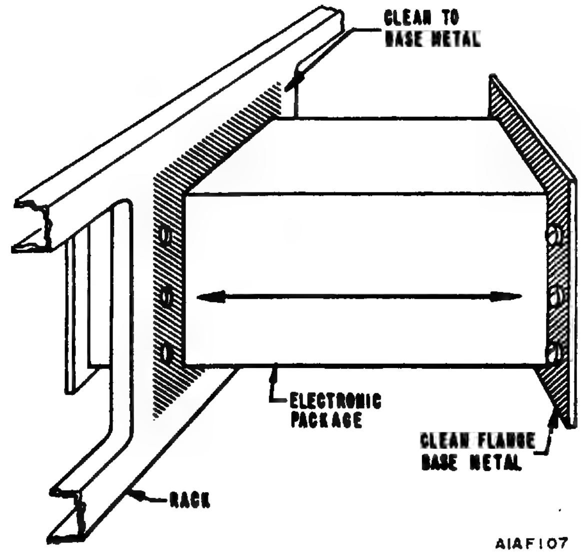


Figure 7 - 29. Typical Method of Bonding Between Attaching Flange of Electronic Package and Rack

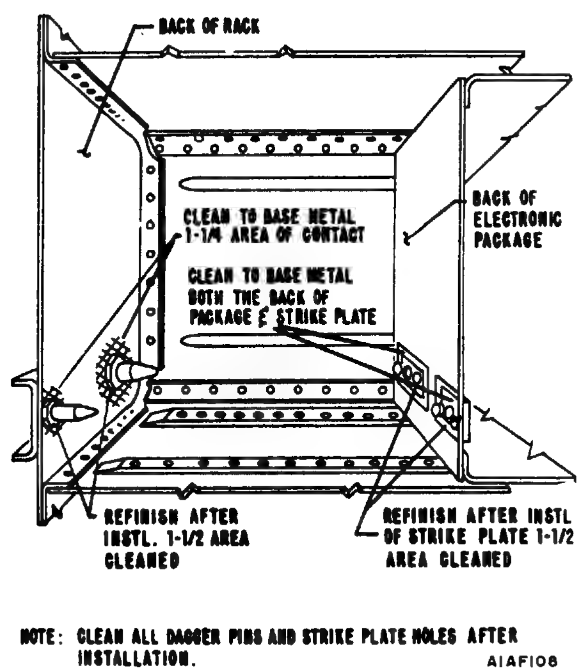
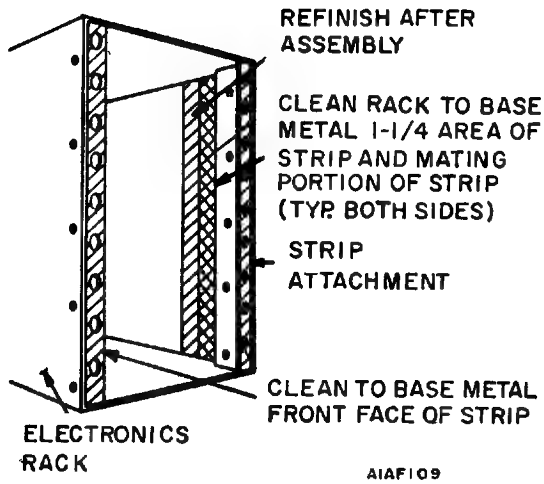
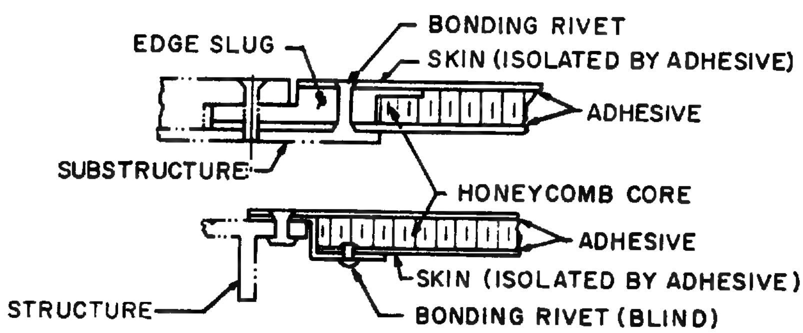


Figure 7 - 30. Typical Method of Bonding with Dagger Pins





NOTES:
1. USE A MINIMUM OF TWO RIVETS (TOTAL AREA ELECTRICALLY EQUIVALENT TO TWO 1/8 IN. DIAMETER RIVETS) FOR ANY ONE CONNECTION. INDICATE THE TOTAL NUMBER OF RIVETS AND RIVET SPACING ON THE INSTALLATION DRAWING
2. DRILL HOLES FOR ALL RIVETS AND INSTALL RIVETS AFTER ADHESIVES ARE CURED.

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Figure 7 - 32. Typical Bonding of Details Which are Isolated by Adhesives

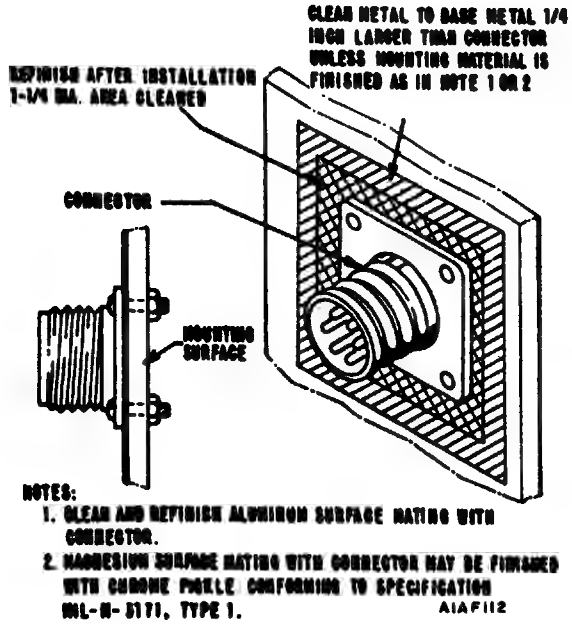


Figure 7 - 33. Typical Method of Bonding Through Bolted Connection

7.4.4 Bonding Practices Summarized

a. Permanent-type bonds are more reliable than the semipermanent type, and are therefore preferred.

b. Direct-type bonds, such as formed by individual welded, sweated, or brazed joints are, in general, bonds of lower impedance than indirect types, and are therefore preferred.

c. Where bond joints exist between dissimilar metals, finished bond joints should have a protective coating such as a suitable grease or polysulphate to exclude moisture and retard corrosion.

d. Bonds should afford good metal-to-metal contact over the entire mating surfaces of the bond joint. The mating surfaces should be clean and free from any nonconductive finishes. Bare, clean, metal-to-metal contact will ensure a low-impedance connection between mating surfaces.

e. Indirect bonding conductors should preferably be in strap form, broad in width, thin, and as short in length as possible to afford desirable low-impedance electrical connections at radio frequencies. The length-to-width ratio of the bond straps should be less than 5:1.

f. The strap type of bond connection provides flexibility, sometimes necessary because of vibration, expansion, contraction, hinges, and equipment misalignment arising from normal fabrication and installation tolerances.

g. Where bonds must afford shielding integrity, permanent-type metal-to-metal joints, afforded by welding, brazing, or sweating, are preferred to semipermanent joints that depend on clamping pressures and/or conducting gaskets.

h. A soldered bond-joint should not depend on the solder for mechanical strength. The parent mating materials of the bond should be mechanically jointed by other means such as bolting or riveting.

i. Bonding connections should be located in protected and accessible areas, where practical, to permit ready inspection and replacement if necessary.

7.4.5 Bonding Calculations

Because of the working nature of a bond, it must be capable of carrying potentially large fault or transient currents, be of low resistance and inductance at all frequencies of interest. The DC resistance and the inductance of simple wire forms are given below:

a. For a straight conductor the DC resistance is

$$R = \frac{\rho \ell}{A} \text{ ohms} \tag{7-1}$$

where:

ρ copper = 1.724×10^{-6} ohm-cm
ρ steel = 15×10^{-6} ohm-cm
ℓ = length in cm
A = cross sectional area in cm^2.

The AC resistance R_{AC} increase is given by the relation

$$\frac{R_{AC}}{R_{DC}} \approx D\sqrt{f} \tag{7-2}$$

where:

D = diameter of conductor in inches
f = frequency in Hz

b. The self-inductance of a round conductor is

$$L = 0.002\,\ell \left[2.3 \log \frac{2\ell}{r} - 1 + \frac{\mu}{4}\right] \text{ microhenries } (\mu h) \tag{7-3}$$

where:

ℓ = length in cm
r = radius in cm
μ = permeability of material = 1 for copper.

For wire of rectangular cross section of copper

$$L = 0.002\ell\left[2.3 \log \frac{2\ell}{B + C} + \frac{1}{2} + 0.22\left(\frac{B + C}{\ell}\right)\right] \quad \mu h \tag{7-4}$$

where:
- B = width in cm
- C = thickness in cm
- ℓ = length in cm

The last term may be neglected for $\ell > 50(B+C)$.

The maximum fractional decrease of the inductance as the frequency is indefinitely increased for copper wire is

$$(\Delta L / L)_{\infty} = -1/4 \log \frac{2\ell}{r} - 3 \tag{7-5}$$

where:
- r = radius of wire in any units
- ℓ = length of wire in any units
- L = DC inductance of the wire

and the limiting inductance as frequency increases (for copper) is

$$L' = 0.002\,\ell \left[2.3 \log \frac{2\ell}{r} - 1\right] \quad \mu h \tag{7-6}$$

c. A solution for R_{AC} of a flat thin copper strap can be approached by shaping it into a hollow tube. Then

$$R_{AC} = \frac{4.15}{r} \times 10^{-8} \left(1 + \frac{t}{2ar}\right) \sqrt{f} \quad \text{ohms/cm} \tag{7-7}$$

where:
- r = outer radius of the tube - cm
- t = thickness of strap - cm
- a = $\frac{.2142}{2} \sqrt{f}$ ohms/cm and f is in hertz

and where a is large

$$R_{AC} = \frac{4.15}{r} \times 10^{-8} \sqrt{f} \text{ ohms/cm} \tag{7-8}$$

The formulas are for isolated conductors and do not consider the contact resistances or impedances of mating surfaces. Since a DC resistance check with a voltohmyst of mating surfaces or bonds is doubtful, a good rule of thumb is to use a Shallcross bridge and check that the contact resistance of the bond or other device is less than 0.0025 ohm. The bond itself should be as short as possible, and broad, or as great cross sectional area as possible.

As a sample calculation, the DC resistance of a ten-foot section of 1/4 in. x 2-1/2 in. copper bus is

$$R = \frac{\rho \ell}{A} = \frac{\rho \ell}{B \times C} \tag{7-9}$$

$$R = 1.724 \times 10^{-6} \quad \times \quad \frac{10 \times 2.54 \times 12}{2.5 \times 0.25 \times 2.54^2}$$

$$R = 130 \ \mu \text{ohms}$$

An equivalent length of 4/0 wire yields

$$R = 500 \ \mu \text{ ohms}$$

The inductance of the bus is

$$L = 0.002 \times 10 \times 12 \times 2.45 \ [\ 2.3 \log \frac{2 \times 10 \times 12}{2.75} + \tfrac{1}{2}\ ]$$

$$L = 0.610\ (4.45 + 0.5)$$

$$L = 3\ \mu h$$

For the 4/0 cable

$$L = 0.002 \times 3.05\ [\ 2.3 \log \frac{2 \times 10 \times 12}{0.264} - 0.75\ ]$$

$$L = 0.610\ (6.8 - 0.75) = 3.7\ \mu h$$

A knowledge of the electrical parameters of any planned grounding system is of immeasurable help in precluding problems areas. Such simple calculations permit setting up equations for the entire system to be connected to the ground grid. Results of calculations of inductance for bonds of various width to length ratios are shown in figure 7-34. The impedance of a typical bond of length to width ratio of 5.5 to 1 is shown in figure 7-35 for both measured and calculated data.

The calculated data is derived from the formula for the minimum inductance at the highest possible frequency and, hence, is slightly lower than the measured value.

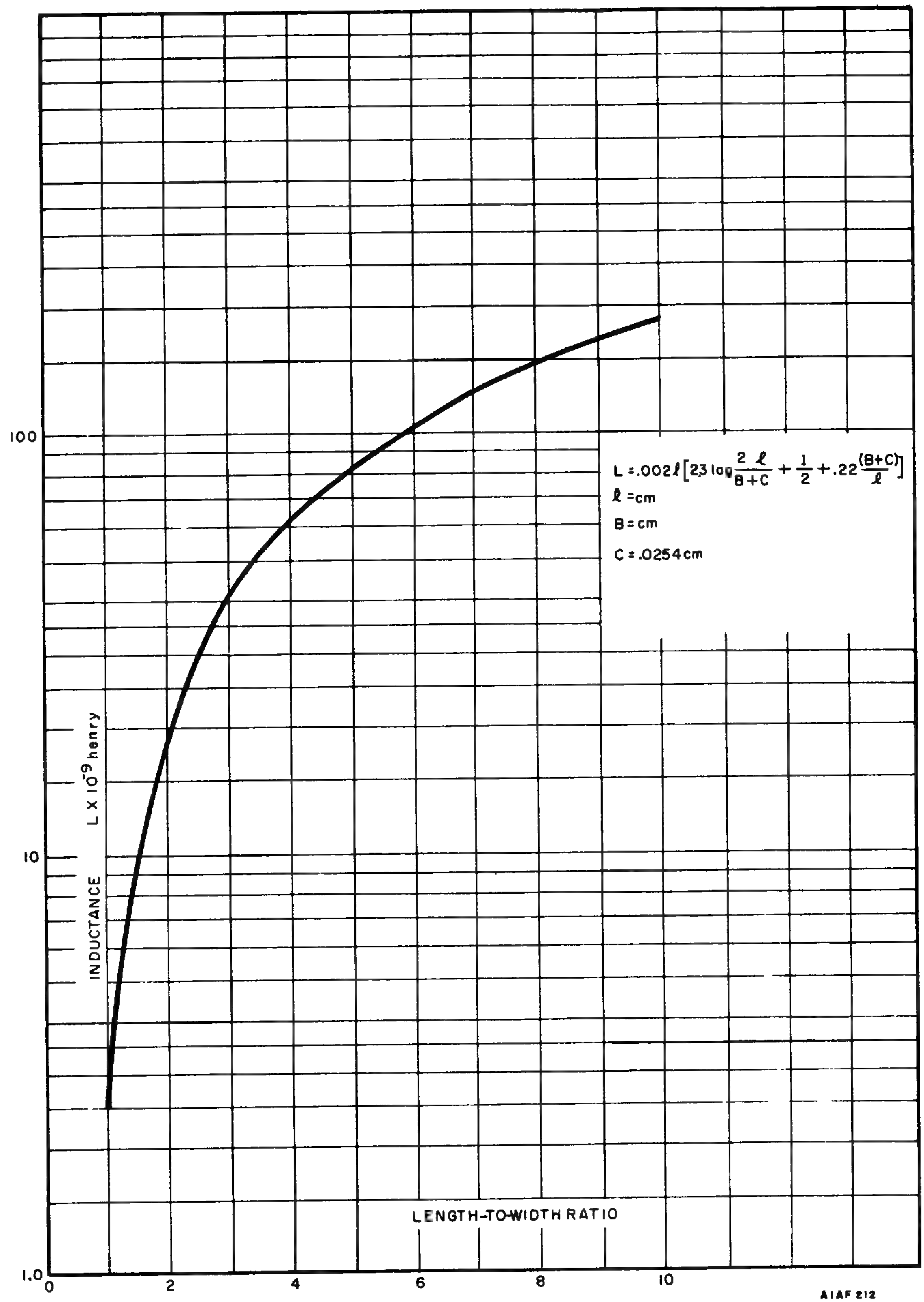


Figure 7 - 34. Theoretical Inductance Values with Varying Bond Length - to - Width Ratios

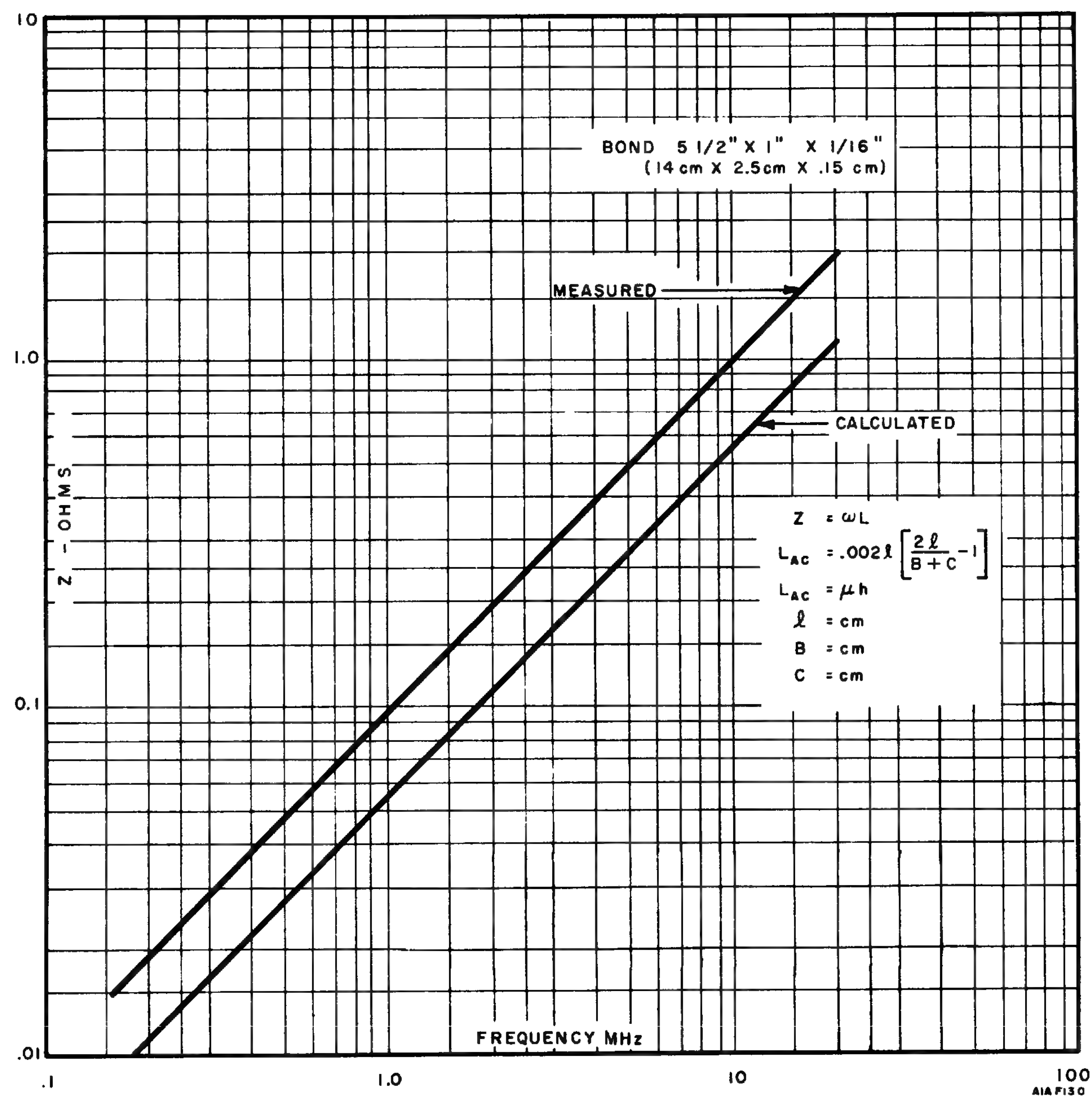


Figure 7-35. Measured and Calculated Values for a Bond Strap

7.5 SHIELDING

7.5.1 Basic Considerations

To preclude the possibility of EMI and RADHAZ problems, the installation designer should take advantage of all inherent shielding which the installation or system and its individual equipments as well as terrain, has to offer. Items such as building walls, partitions, towers and other similar structures may be used to advantage. The shielding effectiveness afforded by these items may be used to isolate EMR generating equipment from potentially susceptible devices, personnel, flammable mixtures, and other items. In addition, equipments used in a console or rack may be placed to take advantage of the inherent shielding of that rack.

Shielding can be very complicated or quite simple depending upon the particular installation under consideration. Fixed ground equipments, except those of extremely high sensitivity, are relatively easy to shield. Generally, mobile systems pose special problems because the individual equipments must be mounted close together resulting in all of the energy being concentrated near susceptible devices. In addition, the energy may be directed in the vicinity of personnel, fueling or ordnance handling areas. Extremely sensitive, as well as high powered equipments, also present special shielding problems. In addition, the more electronic equipments used on an installation the more difficult the shielding problem becomes, regardless of how well the shielding is designed.

A good shield must have the following general characteristics:

a. It must contain undesired EMR generated by source equipment.

b. It must permit only such undesired energy to pass that will not interfere with performance of adjacent equipment or create hazardous situations as described in this handbook.

c. It must prevent externally generated EM energy from degrading or damaging electronic or electrical equipments.

If it were not for the many mechanical and electrical interfaces required in an installation and its equipments, the shielding problem would be reduced to choosing a proper shield material and applying it. Since each interface degrades the shield to some degree, the selection and implementation of techniques to provide continuity at these interfaces is important. Figure 7-36 illustrates some of these interfaces. Despite the complexity of the problem, a series of principles may be used for the design and use of shields that will be effective in the control of EMR as well as the protection from the effects of the emissions.

7.5.2 Shielding Effectiveness

The shielding effectiveness (SE), or insertion loss, expressed in dB, attenuation, can be generalized as follows:

$$SE = A + R + K \tag{7-10}$$

A = Absorption loss for both sides (dB)

R = Reflection loss for both sides (dB)

K = Correction factor for waves reflecting inside wall. This factor is insignificant for metal walls of enough thickness to support their own weight.

a. Absorption loss. This factor represents the reduction in signal due to dissipation as it proceeds through the body of the shield and is calculated by the following formula:

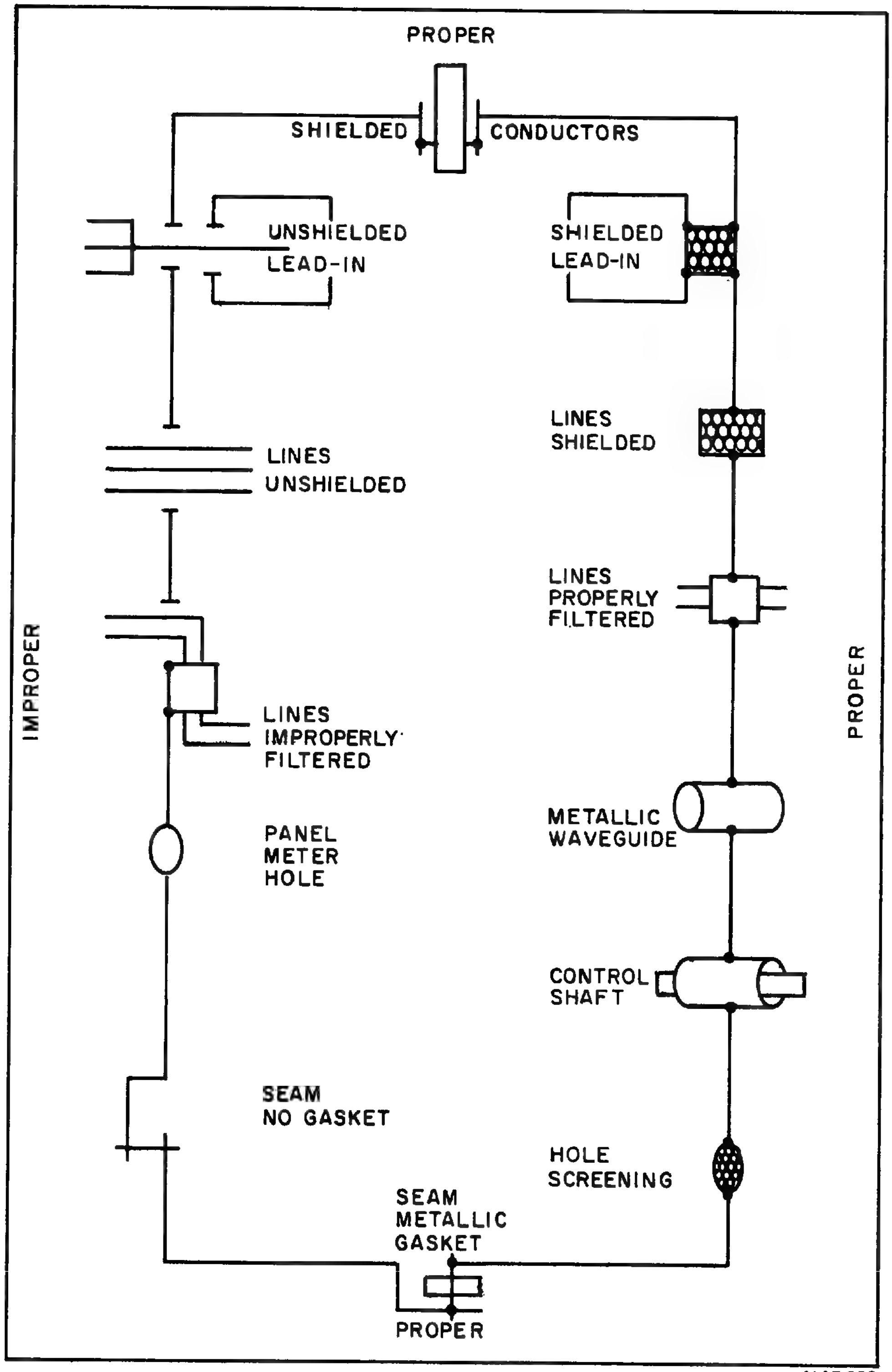


Figure 7 - 36. Typical Shielded Compartment Interfaces with Proper and Improper Controls

$$A = 3.338 \times 10^{-3}\ T \sqrt{F\ \sigma\mu} \qquad (7\text{-}11)$$

A = Wall absorption loss (dB)

T = Wall thickness in mils

F = Frequency in hertz

σ = Material conductivity relative to copper

μ = Material magnetic permeability (vacuum = 1)

Figure 7-37 is presented to assist the designer in determining, for various magnetic and nonmagnetic materials, the penetration or absorption loss at a chosen frequency. For a desired amount of absorption loss at a known frequency, the required thickness for a known metal may be determined as follows:

(1) Locate the frequency on the F scale and the desired absorption loss on the A scale. Place a straightedge across these points and locate a point on the unmarked scale (Example: A=10 dB, F=100 kHz).

(2) Pivot the straightedge about the point on the unmarked scale to various metals noted on the $\mu \times \sigma$ scale. A line connecting the $\mu \times \sigma$ scale and the point on the unmarked scale will give the required thickness on the T scale. Example: for copper T = 9.2 mills, for commercial iron T=5.2 mils.)

The figure may also be used in reverse of the above order to determine absorption loss of a known thickness and metal.

Although the shielding effectiveness due to the absorption loss at low frequencies drops off considerably, this is of little consequence since the configuration is not likely to be an efficient receiving aperture at these frequencies.

b. Reflection Loss. As an electromagnetic wave propagates from free space into another medium, such as a metallic barrier, the wave impedance will change suddenly and reflection will occur at the boundary of the two media.

For plane waves, shielding magnetic material provides the best absorption loss (since $\mu \gg \sigma$ at a given thickness T) while good conductors provide better reflection loss ($\sigma \gg \mu$). To calculate reflection loss for plane waves the following equation or figure 7-38 can be used.

$$R_p = 168 + 10 \log \frac{\sigma}{\mu\ F} \text{ in dB} \qquad (7\text{-}12)$$

In determining plane wave reflection loss R_p:

o Locate a point on the σ/μ scale for one of the metals listed. If the metal is not listed, compute σ/μ and locate a point on the numerical scale.

o Place a straightedge between the σ/μ scale and the desired frequency on the "F" scale.

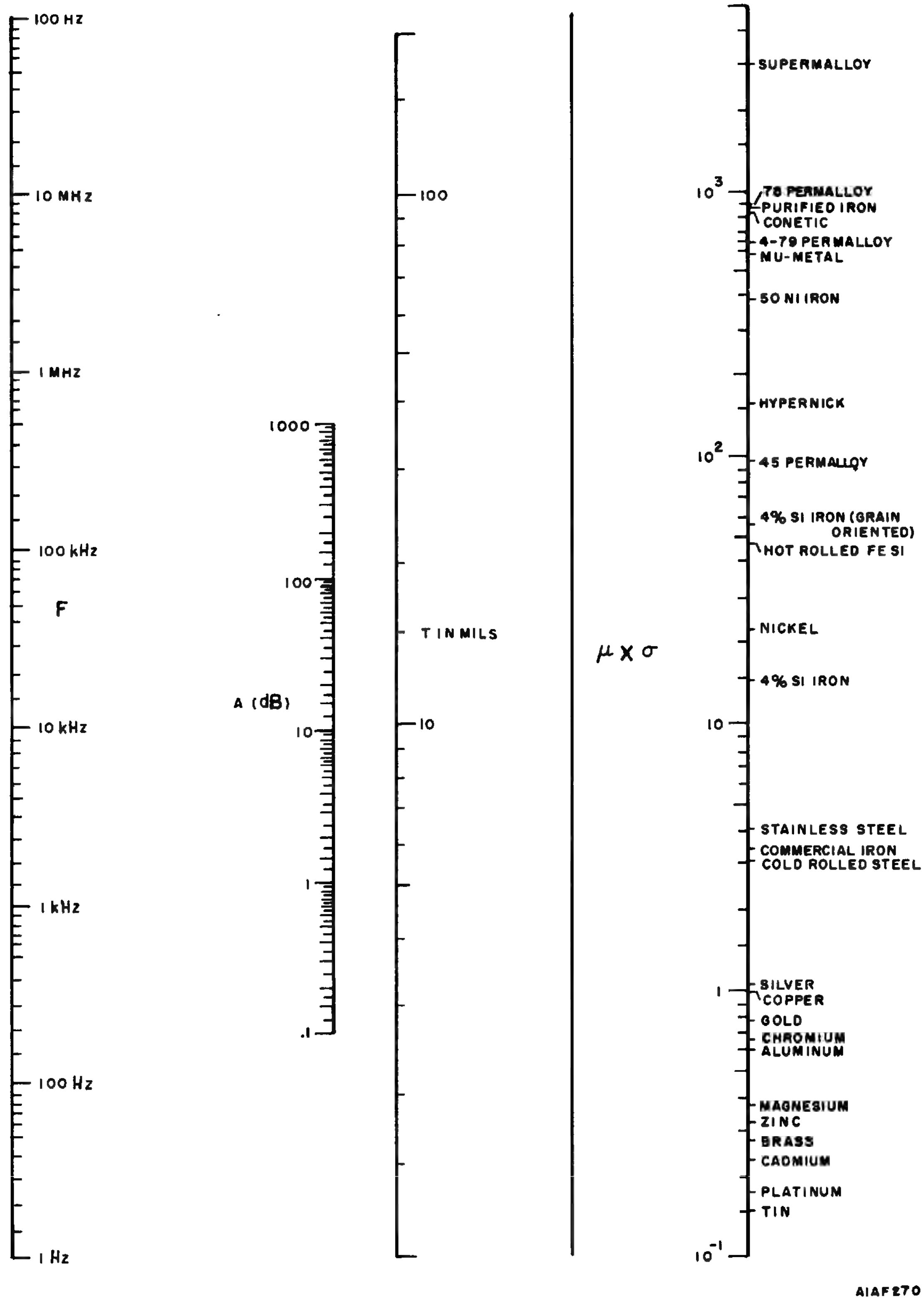


Figure 7 - 37. Absorption Losses (A)

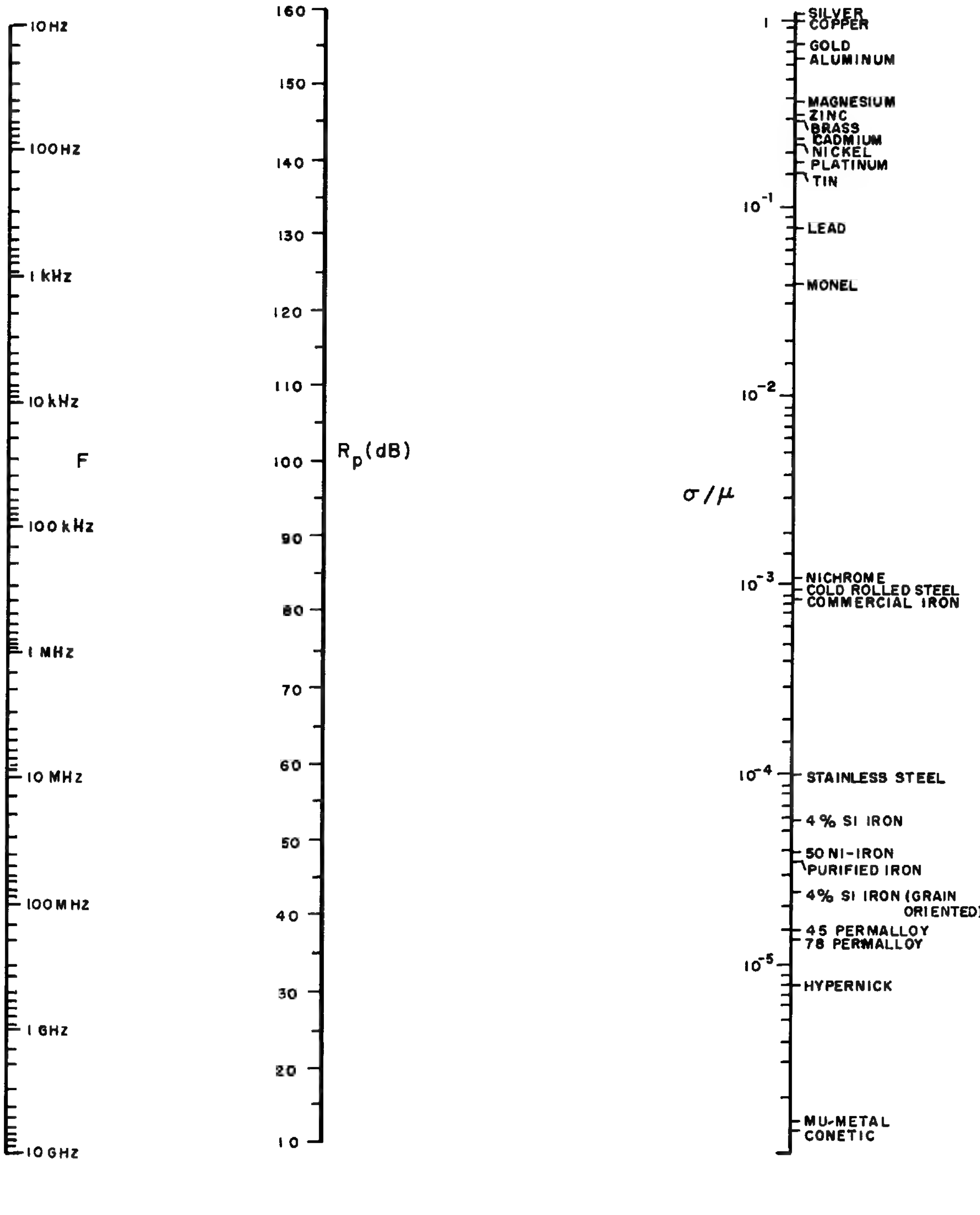


Figure 7 - 38. Plane Wave Reflection Losses R_p

o Read the plane wave reflection losses from the R_p scale.

The electric field that exists close to the radiating antenna is high in impedance and is more in keeping with the nature of the radiating elements within an equipment group. The reflection loss for the high impedance or E-field wave can be calculated with the following equation or from the nomograph in figure 7-39.

$$R_e = 353.6 + 10 \log \frac{\sigma}{F^3 \mu D^2} \text{ (dB)} \tag{7-13}$$

D = Distance from radiating element to shield (inches)

Both R_e and R_h (see below) can be computed using the following steps:

o Locate a point on the σ/μ for one of the metals listed. If the metal is not listed, compute σ/μ and locate a point on the numerical scale.

o Locate the distance between the energy source and the shield on the "D" scale.

o Place a straightedge between D and σ/μ and locate a point on the blank scale.

o Place a straightedge between the point on the blank scale and the desired frequency on the F scale.

o Read the reflection loss from the R_e or R_h (figure 7-40) scale.

o By sweeping the F scale while holding the point on the blank scale, R_e or R_h versus frequency can be obtained.

The magnetic field is known as a low impedance field. Magnetic field shielding may best be achieved through the use of magnetic material such as mu-metal, permalloy, steel, etc. The reflection loss for magnetic fields can be calculated with the following equation or from the nomograph on figure 7-40.

$$R_h = 20 \log \left[\frac{0.462}{D} \sqrt{\frac{\mu}{F\sigma}} + 0.136D \sqrt{\frac{F\sigma}{\mu}} + 0.354 \right] \text{ (dB)} \tag{7-14}$$

c. Correction Factor, K. This factor, described earlier, is usually applied when the absorption losses are less than 10 dB. Figure 7-41 gives approximate values of K up to 300 mils of metal thickness. This figure is obtained by plotting data given in table 7-6 for copper magnetic field shielding. From this type of graph any correction factor can be calculated between 60 Hz and 1 MHz.

7.5.3 Shielding Materials

It is noted that magnetic fields are difficult to shield at low frequencies since the reflection losses may approach zero at certain combinations of material and frequency; also, with decreasing frequency, reflection and absorption losses decrease for nonmagnetic metals. At high frequencies, the shielding efficiency is good because of the reflection at the discontinuity in media and the rapid dissipation of the field by absorption. The high theoretical values of shielding effectiveness for magnetic materials are seldom achieved in practice. Some success has been achieved with the use of multiple permalloy shields separated by copper shields, since the shielding effect at these frequencies is largely due to reflection. Copper clad steel is sometimes used for this same reason. Multiple shields may provide reflection losses as high as 100 dB, if the shields are isolated from one another or connected at most at one common point.

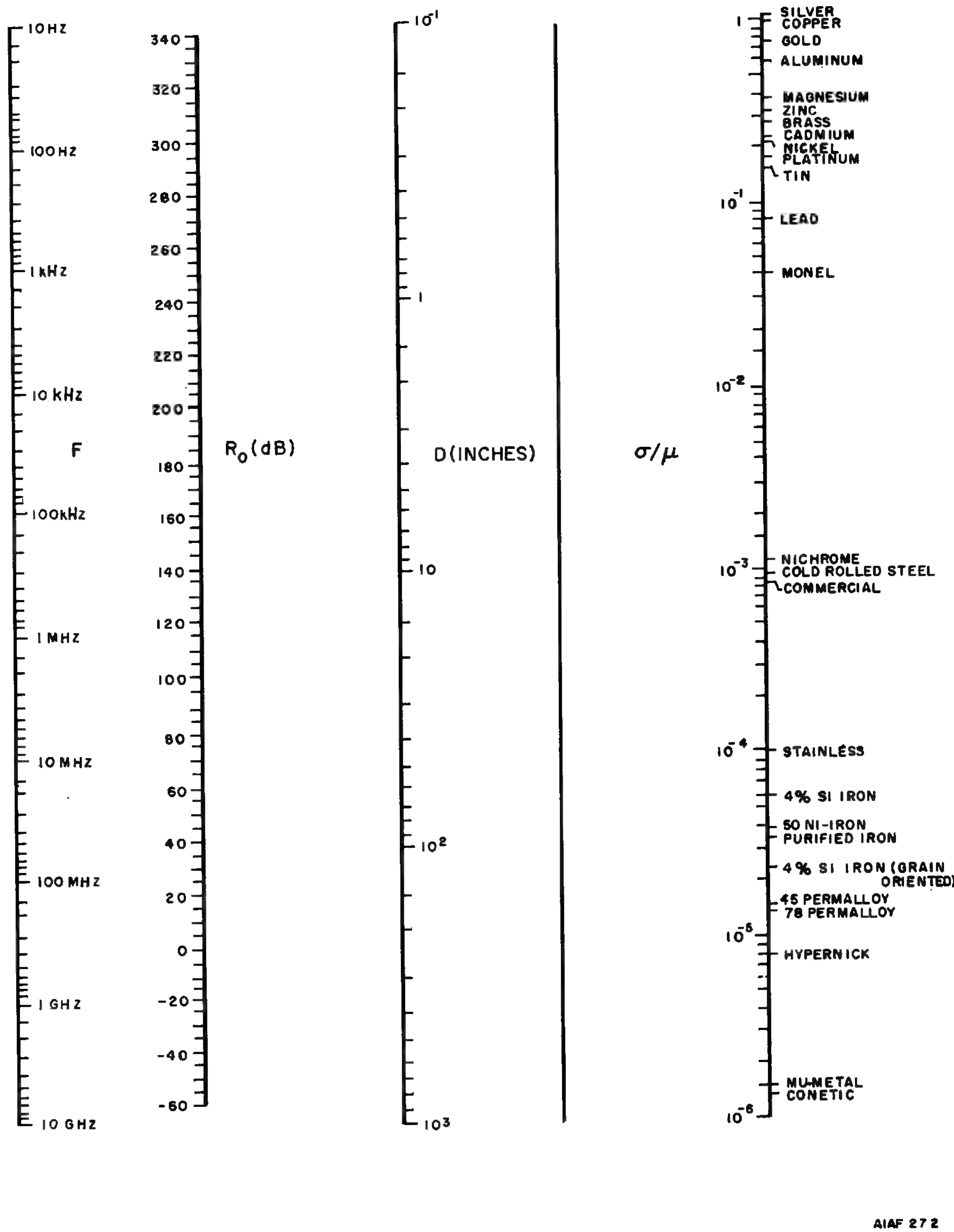


Figure 7 - 39. Electric Field Reflection Losses R_e

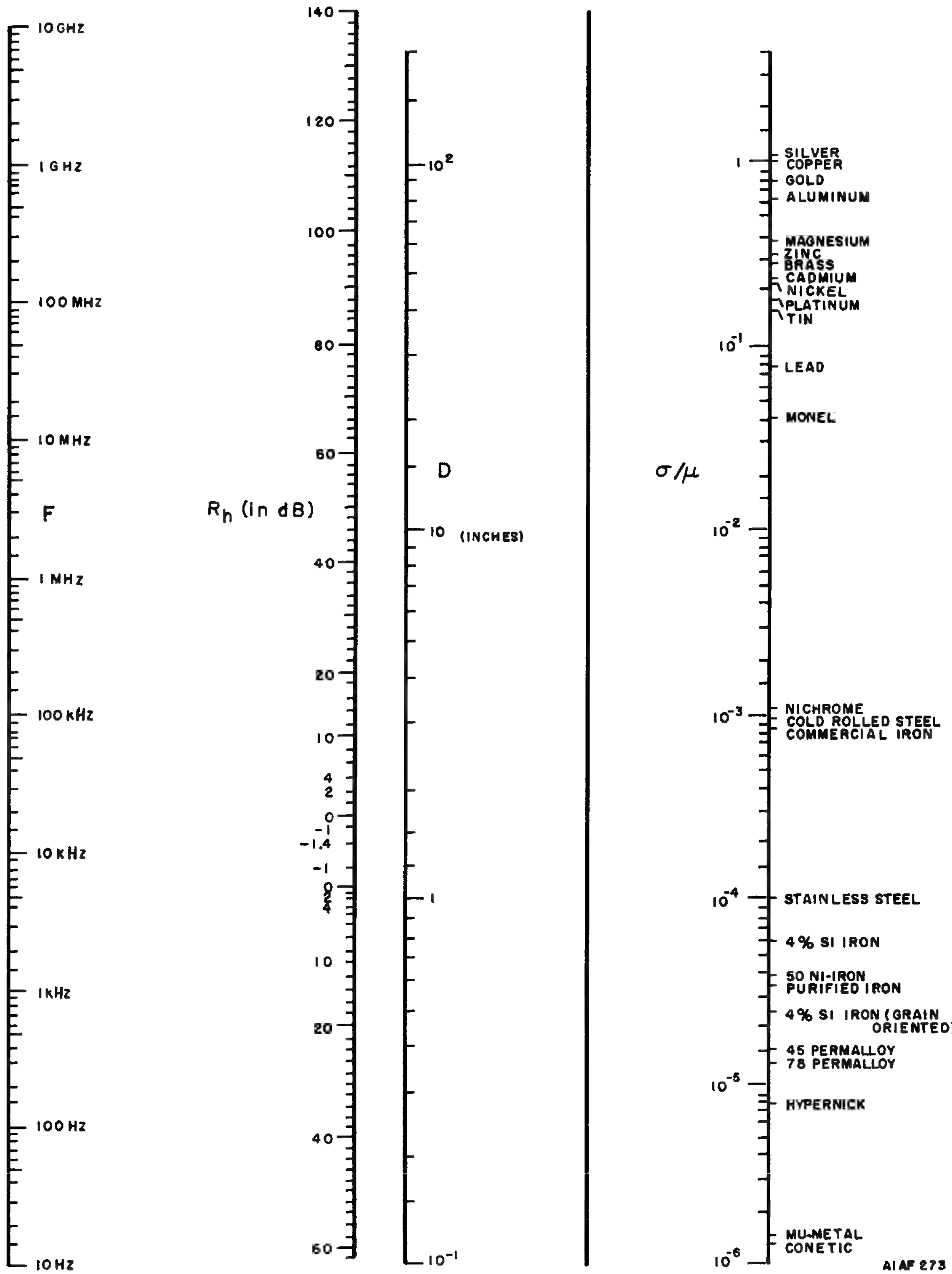


Figure 7 - 40. Magnetic Field Reflection Losses R_h

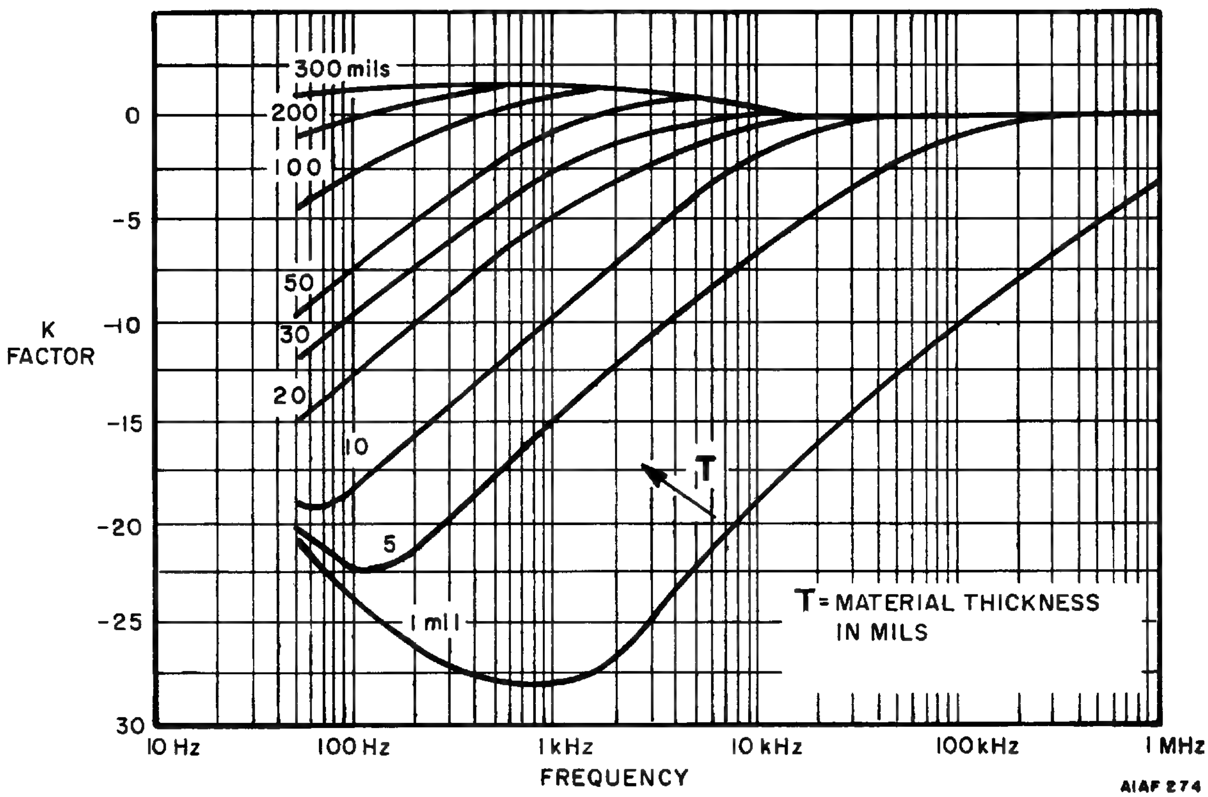


Figure 7-41. Graph of K Correction Factor for Copper Magnetic Field

Table 7-6. K Correction Factors in dB for Solid Metal Shield

	SHIELD THICKNESS (MILS)	FREQUENCY 60 Hz	100 Hz	1 kHz	10 kHz	100 kHz	1 MHz
MAGNETIC FIELDS COPPER ($\mu = 1, \sigma = 1$)	1	-22.22	-24.31	-28.23	-19.61	-10.34	-2.61
	5	-21.30	-22.07	-15.83	- 6.98	- 0.55	+0.14
	10	-19.23	-18.59	-10.37	- 2.62	+ 0.57	-
	20	-15.85	-13.77	- 5.41	+ 0.13	- 0.10	-
	30	-12.55	-10.76	- 2.94	+ 0.58	-	-
	50	- 8.88	- 7.07	- 0.58	-	-	-
	100	- 4.24	- 2.74	+ 0.50	-	-	-
	200	- 0.76	+ 0.05	-	-	-	-
	300	+ 0.32	+ 0.53	-	-	-	-
ELECTRIC FIELDS AND PLANE WAVES COPPER ($\sigma = 1, \mu = 1$)	1	-41.52	-39.31	-29.38	-19.61	-10.33	-2.61
	5	-27.64	-26.46	-15.82	- 6.96	- 0.55	+0.14
	10	-21.75	-19.61	-10.33	- 2.61	+ 0.57	-
	20	-15.99	-13.92	- 5.37	+ 0.14	- 0.10	-
	30	-12.73	-10.73	- 2.90	+ 0.58	-	-
	50	- 8.81	- 6.96	- 0.55	+ 0.14	-	-
	100	- 4.08	- 2.61	+ 0.51	-	-	-
	200	- 0.62	+ 0.14	-	-	-	-
	300	+ 0.41	+ 0.58	-	-	-	-
MAGNETIC FIELDS IRON ($\mu = 1000$, $\sigma = 0.17$)	1	+ 0.95	+ 1.23	- 1.60	- 1.83	-	-
	5	+ 0.93	+ 0.89	- 0.59	-	-	-
	10	+ 0.78	+ 0.48	+ 0.06	-	-	-
	20	+ 0.35	+ 0.08	-	-	-	-
	30	+ 0.06	- 0.06	-	-	-	-
	50	-	-	-	-	-	-
ELECTRIC FIELDS AND PLANE WAVES IRON ($\mu = 1000$, $\sigma = 0.17$)	1	-19.53	-17.41	- 8.35	- 1.31	-	-
	5	- 6.90	- 5.17	+ 0.20	-	-	-
	10	- 2.56	- 1.31	+ 0.36	-	-	-
	20	+ 0.16	+ 0.54	-	-	-	-
	30	+ 0.58	+ 0.42	-	-	-	-
	50	+ 0.13	-	-	-	-	-

a. Material Thickness. It is commonly assumed that most materials which have adequate structural rigidity will also possess sufficient thickness to provide satisfactory shielding effectiveness. While this is an adequate approximation in the radio-frequency range, this does not necessarily hold true for equipments operated in the audio frequency range if high intensity fields are involved. At these frequencies a high permeability material, such as mu-metal, or permalloy is normally required, to provide good shielding efficiency to magnetic fields. When such magnetic shields are used, reflection losses may be obtained even at very low frequencies. Since the shielding effect at these frequencies is a result of surface reflections and not of absorption, the thickness of the shield at that frequency will not be of significance.

b. Non-Solid Shields. There are many applications in which the shield cannot be made of a solid material due to system design requirements. Screens and perforated materials must be employed if an enclosure must be transparent (e.g., a meter face) or ventilated. Since there is no practical means of calculating the shielding effectiveness of woven materials, the installation engineer is referred to the literature for the attenuation characteristics of the various materials and configurations. Often, the exact situation may not be treated sufficiently; therefore, measurements will be required to validate the material and configuration intended for use in the system or installation. In general, the shielding effectiveness of woven materials for radiated fields decreases with increasing frequency, and the shielding effectiveness increases with the density of the weave.

In the induction field where the magnetic component is large, the shielding effectiveness increases with frequency, with the density of the woven material, and with the permeability of the material. Table 7-7 shows the magnetic field attenuation versus frequency for two common types of wire mesh cloth, one made of copper and the other of galvanized steel. The radiated field attenuation of these wire mesh cloth materials is shown in table 7-8.

Table 7-7. Wire Mesh Cloth: Magnetic Field Attenuation vs Frequency

FREQUENCY (MHz)	COPPER		GALVANIZED STEEL	
	18 x 18	22 x 22	22 x 22	26 x 26
	(Attenuation in dB)		(Attenuation in dB)	
0.01	59.3	65.4	94.1	100.3
0.03	70.0	76.1	101.3	107.4
0.06	76.7	82.8	104.0	110.1
0.1	81.1	87.2	105.4	111.5
0.3	90.3	96.4	106.7	112.8
0.6	94.7	100.8	107.0	113.1
1.0	97.0	103.1	107.1	113.2
3.0	99.8	105.9	107.3	113.4
6.0	100.6	106.7	107.3	113.4
10.0	100.8	106.9	107.3	113.4
30.0	101.2	107.2	107.3	113.4
60.0-10GHz	101.2	107.2	107.3	113.4

Table 7-8. Wire Mesh Cloth: Radiated Field Attenuation vs Frequency

FREQUENCY (MHz)	COPPER 18 x 18 (Attenuation in dB)	COPPER 22 x 22 (Attenuation in dB)	GALVANIZED STEEL 22 x 22 (Attenuation in dB)	GALVANIZED STEEL 26 x 26 (Attenuation in dB)
0.01	103.6	109.1	137.7	143.9
0.03	104.7	110.2	135.4	141.6
0.06	105.4	110.2	132.1	138.3
0.1	105.4	113.6	129.1	135.3
0.3	105.0	110.5	120.8	127.0
0.6	103.4	108.9	115.1	121.3
1.0	101.3	106.8	110.8	117.0
3.0	94.5	100.0	101.4	107.6
6.0	89.3	94.8	95.4	101.6
10.0	85.1	90.6	91.0	97.2
30.0	75.8	81.3	81.4	87.6
60.0	69.9	75.4	75.4	81.6
100.0	65.6	71.0	71.0	77.2
300.0	55.9	61.4	61.4	67.6
600.0	49.9	55.4	55.4	61.6
1 GHz	45.5	51.0	51.0	57.2
3 GHz	35.9	41.4	41.4	47.6
6 GHz	29.9	35.4	35.4	41.6
10 GHz	25.5	31.0	31.0	37.2

c. Honeycomb Material. Where shielding, ventilation, and strength are required and weight is not a critical condition, honeycomb panels may be used. The shielding effectiveness of honeycomb panels is based on, and predicted by, the attenuation properties of waveguides operated below cut-off. It is a function of the size and length of the waveguide and the number of waveguides in the panel. Table 7-9 indicates the shielding effectiveness of a honeycomb panel constructed of steel with 1/8-inch hexagonal openings 1/2-inch long.

Table 7-9. Shielding Effectiveness of Hexagonal Honeycomb Made of Steel With 1/8 - Inch Openings 1/2 - Inch Long

FREQUENCY (MHz)	SHIELDING EFFECTIVENESS (dB)
0.1	45
50	51
100	57
400	56
2,200	47

d. Screened Apertures Calculations. The following equations are to be used when an aperture is covered by some type of screening material, but they can be used for cabinet panels if the aperture is considered to be the panel size and the perforations are the holes in this panel, assuming that perforations are equally spaced. If this is not the case, make the substitution of $C^2 = A/N$, in the following equations. To use the equations all parameters must be calculated in the same units (inches, cm, etc.)

C = Center to center

A = Area

N = Number of holes

T = Thickness of cabinet wall

l_a = Length of aperture

l_p = Length of perforation

(1) Square Perforations over Square Aperture

$$SE = 20 \log \frac{C^2 l_a}{l_p^3} + 27.3 \frac{T}{l_p} \text{ dB} \tag{7-15}$$

Use when there are square perforations in a square section of cabinet panel or a square aperture in the cabinet panel covered with material having square holes or perforations, d_a=Diameter of circular aperture; d_p=Diameter of circular perforation.

(2) Round Perforations over Round Apertures

$$SE = 20 \log \frac{C^2 d_a}{d_p^3} + 32 \frac{T}{d_p} + 2.08 \text{ dB} \tag{7-16}$$

Use when there are round perforations in a circular area of cabinet panel or round aperture covered with a material having round perforations.

(3) Round Perforations over a Square Aperture

$$SE = 20 \log \frac{C^2 l_a}{l_p^3} + 32 \frac{T}{d_p} + 3.83 \text{ dB} \tag{7-17}$$

Use when there are round perforations in a square area of a cabinet panel or when a square aperture is covered with a material having round perforations.

(4) Square Perforations over a Round Aperture

$$SE = 20 \log \frac{C^2 d_a}{d_p^3} + 27.3 \frac{T}{l_p} - 1.76 \text{ dB} \tag{7-18}$$

Use when there are square perforations in a circular area of a cabinet panel or when a round aperture is covered with a material having square perforations.

7.5.4 Preservation of Shielding Integrity

As noted earlier the choice of material depends primarily on the type and degree of shielding performance desired. Paragraph 7.5.2 gave details for use in calculating shielding effectiveness. However, many factors must be considered in the total evaluation for shielding effectiveness. Careful attention must be paid to mechanical design and openings for control and power leads, ventilation, doors and covers, meters, control shafts, seams, and other mechanical features which may introduce electrical discontinuities in the shield. Such openings may permit radiation of electromagnetic energy from transmitters, or permit the introduction of spurious signals into a receiver or sensitive instrumentation. Such should be precluded by a combination of design features which form an effective shielded enclosure. Factors to be considered are outlined. Additional information as required may be obtained from many available reference documents.

a. Seams. It is important to obtain a clean metal-to-metal contact at seams to prevent leakage and radiation of energy. Where possible, such seams should be welded, brazed, or soldered such that the joint is continuous; however, satisfactory results can be obtained with construction utilizing closely spaced rivets, provided that no protective finish or corrosion exists to prevent contact between the mating metal surfaces. Also the finish should be removed between the mating surfaces of removable panels or doors. Several configurations for seams between two metallic members are shown in figures 7-42 to 7-44. Regardless of the type of seam used, the RF impedance of the seam must not differ appreciably from that of the material. If the RF impedance of the seam is relatively high, RF voltages can devolop across the seam from skin currents, permitting RF energy to enter the shielded enclosure. It is usually necessary to use continuous welding of seams to ensure shielding effectiveness.

b. Gaskets. Openings which occur at joints or removable partitions may be shielded effectively by utilizing conductive gaskets. The important properties of resilience and high conductivity can be obtained from commercially available gasket materials. The problems involved in designing gaskets include providing the minimum gasket thickness which will allow for the expected surface discontinuities of the joint, providing correct height and pressure and allowing for the frequency of use of the joint. The gasket materials which are selected must be corrosion resistant, conductive, and possess an adequate degree of strength, resiliency, and hardness. They are available in various configurations, including the round type, rectangular type, and a combination gasket used for sealing against fluid flow as well as radio frequency leakage. Good gasket design includes the following criteria:

(1) Gasket materials used for RF shielding and sealing should have unconnected paths to conduct the current across a joint.

(2) Paths should be evenly spaced over the surface of the gasket material as to make contact with the gasket surfaces when pressure is applied.

(3) Conductors used in gaskets should be relatively stable chemically and have good electrical conductance.

(4) Conductors perform best if they are made in a hard temper to break through the surface of the flanges.

(5) The number of conducting paths per square inch is important in controlling contact pressure.

(6) There is an optimum number of conductors per square inch for every combination of gasket design and conducting material.

(7) The mechanical properties of the metal elements and the sealing agent must be such that after sufficient clamping pressure has been applied to establish electrical conducting paths, the remainder shall be sufficient to provide sealing pressure.

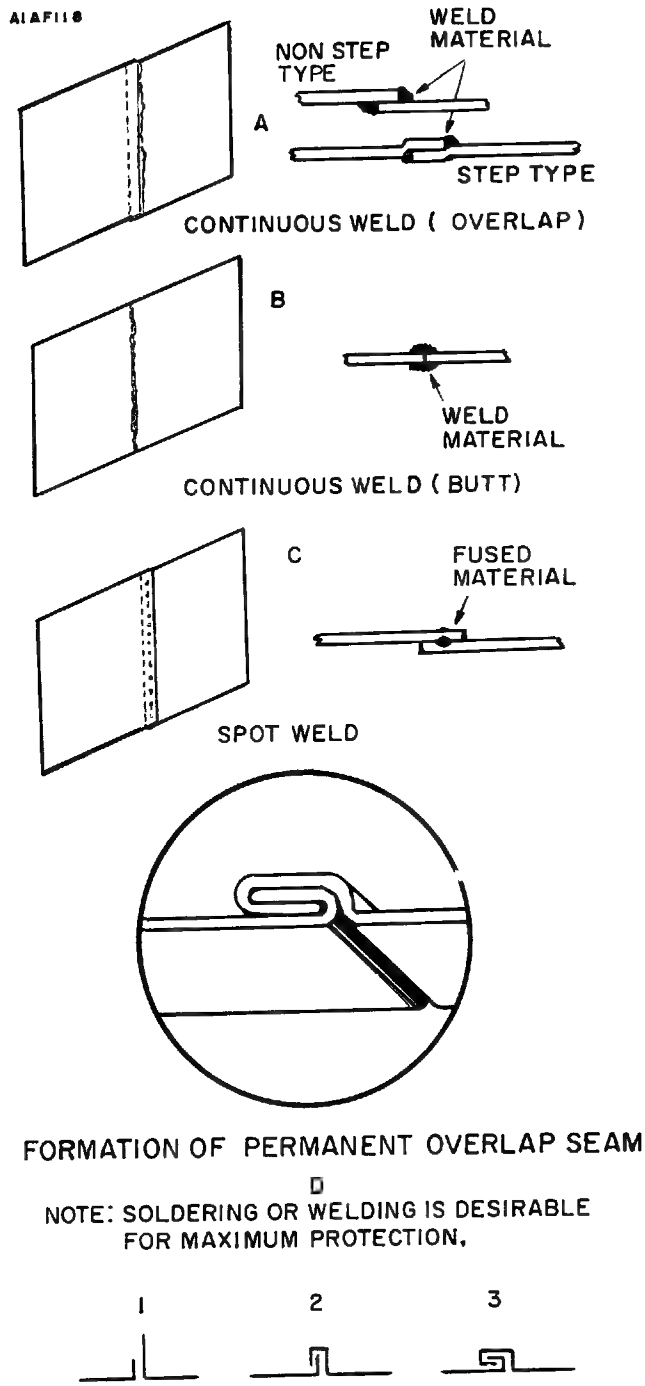


Figure 7 - 42. Panel Seam Configuration

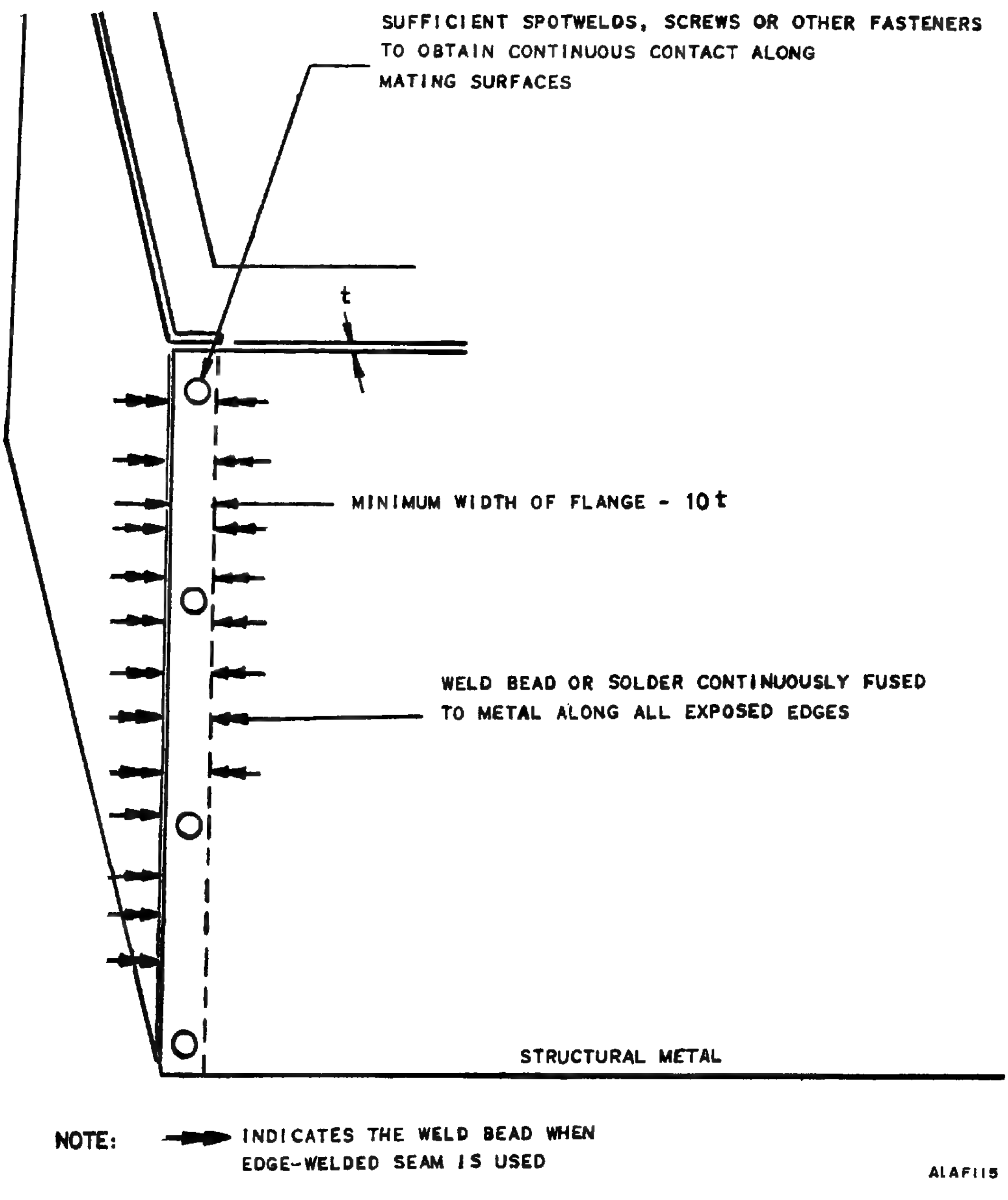


Figure 7 - 43. Seam Design for Minimum Interference

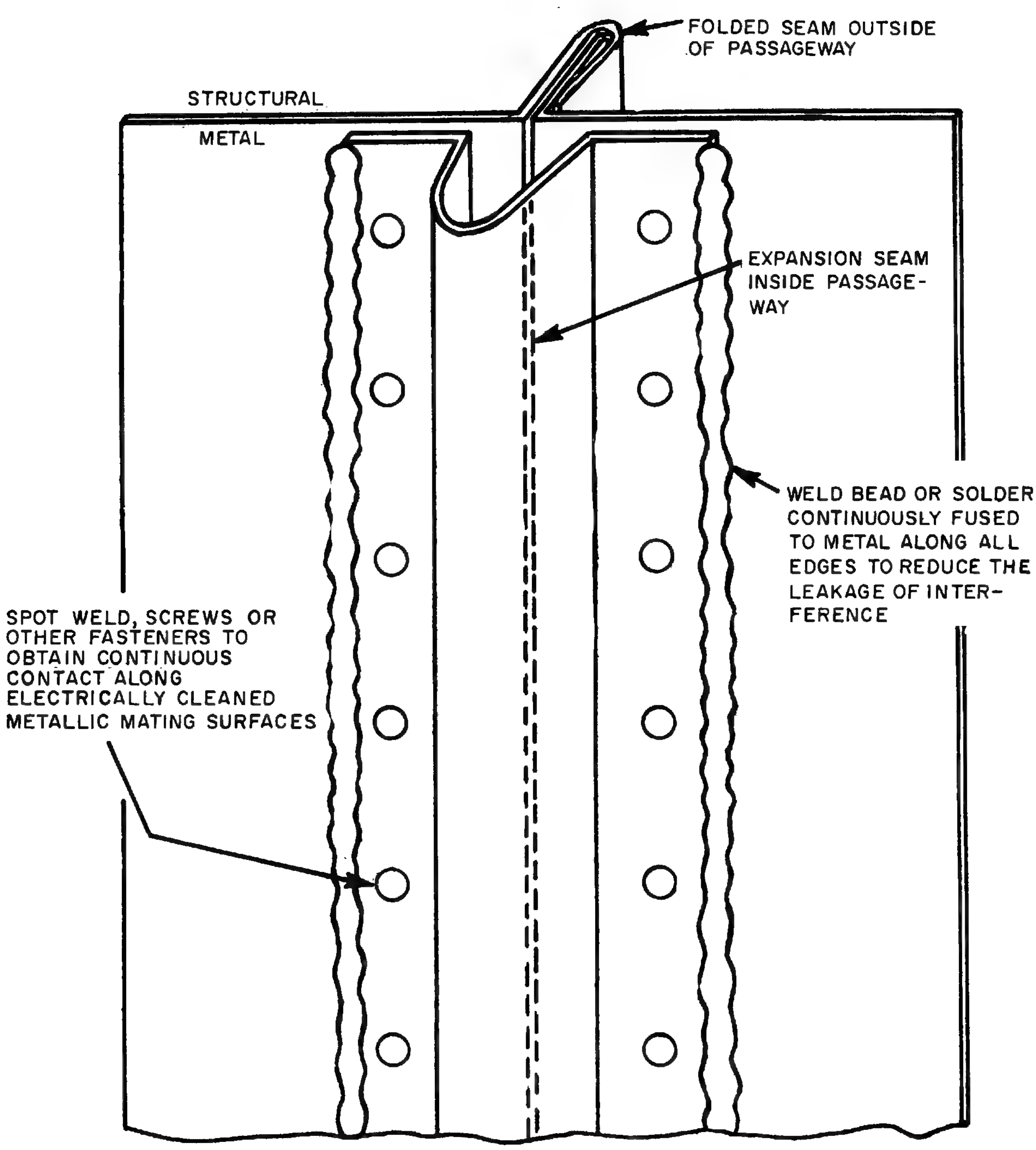


Figure 7 - 44. Vertical Expansion Joint, An Example of a Seam

Figure 7-45 illustrates an acceptable method of making a construction seam using RF gasket material. The features to be observed in the figure are:

"A" - Gasket bonded to one metallic surface of the seam with conductive adhesive; surfaces cleansed of nonconductive material before application.

"B" - Metallic surface machined to smooth finish and all nonconductive materials removed.

"C" - Appropriate mechanical techniques (i.e., clamps, bolts, etc.) used to provide a high pressure on the RF gasket. The pressure must be nearly uniform along the entire length of the seam.

Figure 7-46 illustrates an acceptable method of making construction seams where sections must be removed and replaced for maintenance or loading and handling operations. Table 7-10 is a guide to RF gasket design and usage.

c. Shielded Cables and Fittings. Unshielded and unfiltered conductors entering or leaving an enclosure may completely negate previous shielding efforts. Therefore, it is necessary to provide adequate shielding on all conductors which are likely to carry interference producing currents. The purpose of shielding individual conductors or cables is to prevent radiation or coupling between circuit conductors. The shield may be of solid or flexible conduit or may consist of single or multiple layers of closely-woven metallic braid. The shielding effectiveness of the flexible and mesh material varies with frequency, since at higher frequencies more energy may escape through the shield openings.

It is good practice, and in many systems mandatory, to physically separate pulse cables, and low level signal and control cables. Each signal carrying lead of the cables should be routed through a separate insulated shield. Each shield should be terminated in a separate, low impedance connector, well bonded to the shield. The construction of the connector is very important, for inadequate connectors may radiate at the junction and permit the flow of interference currents on the surface of the shielded cable.

In general, the most important shielded cables of any system or installation are those carrying low level signals and those carrying low level signal circuits to sensitive equipments. The proper installation of these signal cables is essential if interference difficulties are to be avoided.

d. Aperture Design. It is necessary to keep holes for ventilation or drainage of moisture small in effective electrical area to avoid decreasing the shielding efficiency. A "small" hole is one which is small in dimension compared to the operating wavelength. Larger holes should be covered by a fine mesh copper screen, or alternately, a series of small holes may be used.

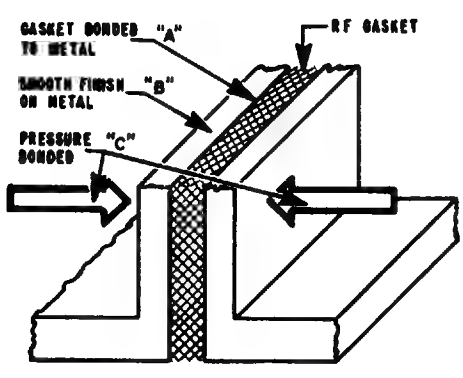


Figure 7 - 45. Acceptable Method of Making Permanent Seam Using RF Gasket

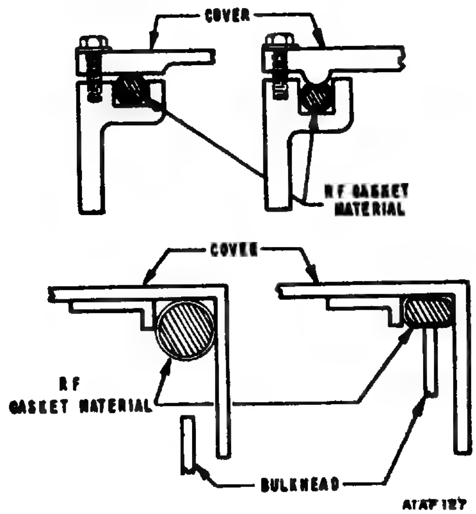


Figure 7 - 46. Covers with Gaskets

Table 7-10. RF Gasket Design and Usage

GASKET CONSIDERATION	DETERMINED BY
Material	Corrosion, mechanical wear, spring qualities, and RF properties
Form	Attachment methods, force available other gasketing functions, joint unevenness, and space available
Thickness	Class of joint, joint unevenness, force available, and RF level

Where screen mesh is used, the mesh should have about a 50 percent open area and 60 or more strands per wavelength. It is important that continuity of the individual wires be preserved at their point of intersection by joining in some manner, so subsequent oxidation will not reduce the shielding efficiency.

Where large openings are required such as for ventilation, these should be equipped with suitable panels to prevent passage of electromagnetic energy. The most efficient type of panel for this purpose consists of honeycomb sections similar to automobile radiator designs, except that the intercellular connections are soldered throughout their length. Shielding may also be provided by layers of copper screening, but lower shielding effectiveness and higher air resistance will result.

An interference reduction technique which may be of value is to design the aperture, through which leakage occurs, as a waveguide-type attenuator, which acts as a high pass filter. For a particular waveguide there exists a cutoff frequency, which is the lowest frequency at which propagation will occur without attenuation. Below cutoff, attenuation is a function of guide length and the frequency. By designing an aperture in a shielded enclosure as a waveguide operating below cutoff for the dominant mode (lowest propagation frequency), from 80 to 100 dB of attenuation can be provided. The most common waveguide apertures are either rectangular or circular openings. As a design guide or approximation for frequencies well below cutoff, making the length 3 times the diameter affords 100 dB of attenuation with circular guides; and 80 dB of attenuation with rectangular guides.

Some commercial signal generators and orifices for screen rooms make use of waveguide attenuators. The waveguide attenuator is also of considerable value when control shafts must extend through an enclosure. By making use of an insulated control shaft passing through the waveguide attenuator, the control function can be accomplished with little possibility of radiation. However, where a metallic control shaft is required, it must be grounded to the case by a close-fitting gasket or metallic fingers. The waveguide attenuator approach may also be considered where holes must be drilled in the enclosure. If the metal thickness is sufficient to provide a "tunnel" with adequate length, a waveguide attenuator is effectively produced. For example, a metal wall 3/16-inch thick would permit a 1/6-inch hole to be used, without excessive leakage. This technique definitely should be considered where it is necessary to confine extremely intense interference sources.

Other openings, such as for fuse receptacles, phone jacks, and meter jacks should be shielded with a removable or spring loaded cap. A panel meter usually requires a fairly large mounting hole and should be provided with a shield which can be made contiguous with the case. Metallized glass for use on meters and other instruments, as well as viewing panels, has been developed which reduces RF leakage through the glass and still results in a light transmission of 70 to 80 percent. Figures 7-47 through 7-49 illustrate acceptable methods for shielding various apertures.

If hinges are used on panels, it is recommended that a mesh such as conductive weather stripping be used on the hinged side of the panel. An alternative method for shielding at the hinge side of the panel is to use metal fingers. The shielding material must be electrically and mechanically bonded to the frame at close intervals to ensure proper shielding.

The best arrangement of spring contact fingers around removable panels or doors calls for the installation of two sets of fingers at right angles to each other. One set is a wiping set; the other is in compression; and the combination makes good electrical contact when the door is closed. The pressure exerted by these springs is highly important and it should be carefully maintained. Cleanliness is also important.

7.5.5 Enclosures

Where possible internal walls and compartments may be used to limit propagation of interference within an enclosure or equipment case. Lead entry and exit should be designed as follows:

a. Isolate leads likely to be noisy (such as power leads) from other leads, or if connectors are used, employ separate connectors.

b. Power input circuit configuration should complement the power and power grounding system into which

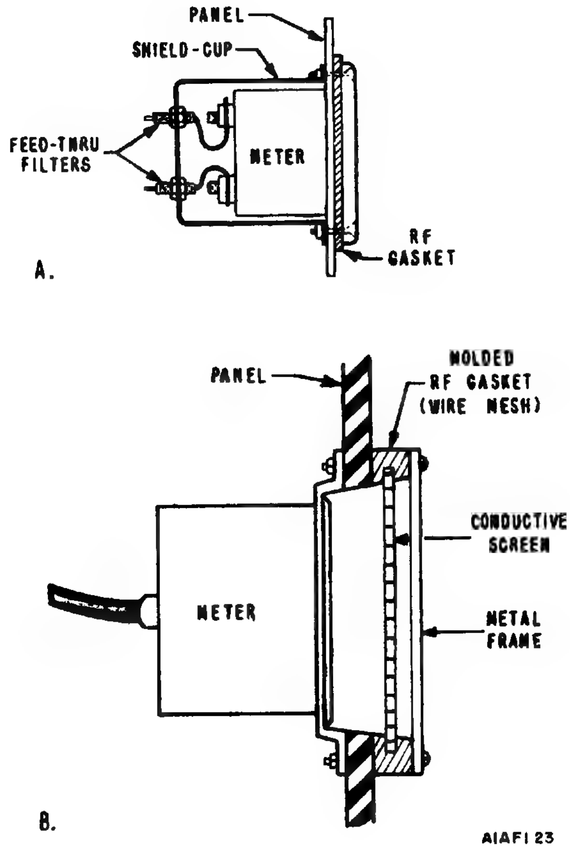


Figure 7 - 47. Acceptable Methods of Shielding Panel-Mounted Meters

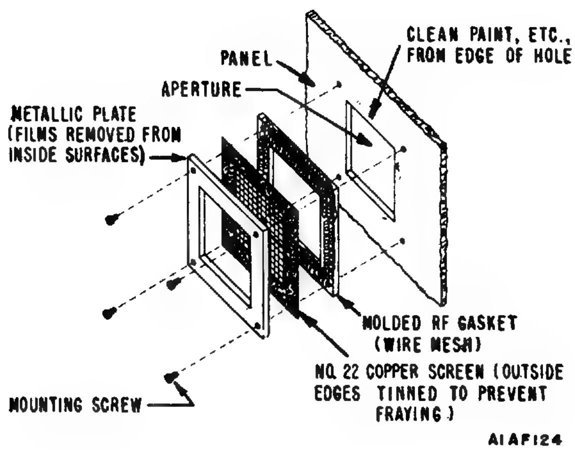


Figure 7 - 48. Method of Mounting Wire Screen Over a Large Aperture

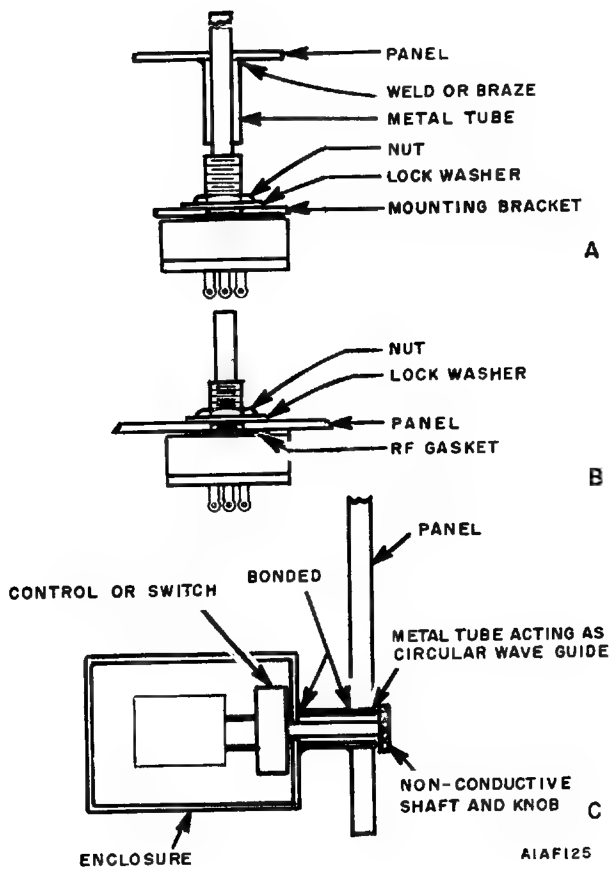


Figure 7 - 49. Acceptable Use of Circular Waveguide in a Permanent Aperture for Control Shaft

the equipment will be integrated. Do not ground a power return lead internally if the total system follows the wired power return concept. Do not use a sensing device or transducer that uses the shield for signal return in a system or subsystem having balanced symmetrical input circuits.

MIL-E-8881 covers shielded enclosures and screened rooms which will provide specified degrees of attenuation from external electromagnetic fields between the frequencies of 100 kHz and 20 GHz. The enclosure is used for testing and alignment of electronic equipment and other such related purposes. The shielding attenuation of shielded enclosures is to be measured in accordance with MIL-STD-285.

7.5.6 Shielding Checklist

The following checklist is furnished as a guide for shielding.

- o Design shielded wires and enclosures to provide maximum shielding efficiency.
- o Use a minimum number of joints, seams, gasket seals, and openings.
- o Use conductive material for gasket seals.
- o Compress all RF gaskets.
- o Use a minimum number of inspection plates, adjustment holes, and screened ventilation parts.
- o Check equipment enclosure for RF leaks through:

  Meters
  Toggle switches
  Indicator lamps
  Fuse holders
  Handles
  Access doors
  Any other such openings

- o Electrically bond screens and honeycomb material to their frame.
- o Whenever possible, electrically bond all discontinuities.
- o Ensure that shielding interfaces with the other EMC disciplines.

7.6 FILTERING

7.6.1 Introduction

The most economical method of controlling emissions is to reduce the level of spurious radiations at the source. The reason for this should be apparent. A single high level spurious radiation from a transmitter may produce interference in a number of receivers. If this spurious output is not reduced to a tolerable level at the transmitter, it will be necessary to provide interference reduction and control techniques at each of the susceptible receivers in order to eliminate the interference.

In general, there are three methods which may be used to reduce the spurious outputs of a transmitter. First, the level of spurious outputs may be reduced considerably by operating the various components in the transmitter in a more linear operating region. However, linear operation impairs the performance of frequency generators and modulators, and reduces the efficiency of amplifiers. Second, shielding as described in 7.5, may be incorporated between circuits to eliminate undesired coupling of signals. Third, the potential interference emissions can be reduced by introducing filters between the various stages of the transmitter to reduce spurious outputs as they are generated, and to restrict the magnitude of this spurious output at the final power amplifier. Filters also play a very important role in receiver design to insure that a receiver has adequate interference rejection.

Many networks may be employed as filters. Some will be described herein, along with other factors which must be considered when using the filters.

7.6.2 Capacitors

Capacitors offer impedance to the flow of alternating current in the form of capacitive reactance (X_c). The formula for capacitive reactance

$$X_c = \frac{1}{2\pi f C} \tag{7-19}$$

shows that the impedance is a function of the rated capacitance and the frequency of the input signal.

- o Capacitive reactance decreases with an increase in the rated capacitance of a capacitor.
- o Capacitive reactance decreases with an increase in the frequency of the signal applied to the capacitor.

Low impedance to the flow of high-frequency alternating currents and the ability to store a charge are the properties of capacitors that make them useful in suppression applications.

The two major types of capacitors used for suppression purposes are the bypass type and the feedthrough type, as shown in figure 7-50. They are distinguished by their internal construction and electrical characteristics; because of resonance effects with lead inductances, the bypass capacitor is limited in frequency range. The feedthrough was developed to overcome this frequency limitation.

The overall superiority of the feedthrough capacitor is illustrated by the curve shown in figure 7-51, which compares the insertion loss of a feedthrough capacitor with a bypass capacitor of the same rated capacitance. At the 100-megahertz point the feedthrough capacitor is about 38 dB, or 100 times more effective than the bypass capacitor. The suppression effectiveness of the feedthrough capacitor nearly approaches the effectiveness of a capacitor with no inductive component. As frequency rises, the insertion loss rises indefinitely. This indicates that the feedthrough capacitor is a broad band suppression device. Feedthrough capacitors are intended for mounting in a grounded through-panel or bulkhead. The capacitor case must make complete circumferential contact with the bulkhead in order to obtain maximum suppression effectiveness. Under these conditions the bulkhead acts as a shield that prevents coupling between output and input signals. Flanged bracket, threaded body, and threaded neck mounting methods provide the degree of contact with the bulkhead that is necessary. A wrap-around bracket should not be used to mount a feedthrough capacitor, since the additional inductance introduced will lower the effectiveness of the feedthrough capacitor to the level of the bypass type. The live terminals on the feedthrough capacitor may be solder lugs or studs. Feedthrough capacitors are similar to small sections of low-impedance coaxial cable. They have an inner conductor that consists of a piece of heavy bus wire surrounded by a dielectric that, in turn, is surrounded by an outer conductor. The inner conductor must always carry the full load current. The feedthrough capacitor is difficult to install in equipment in the field compared with the bypass capacitor. Feedthrough capacitors are described in terms of their current-carrying ability, their working voltage rating, and their capacitance.

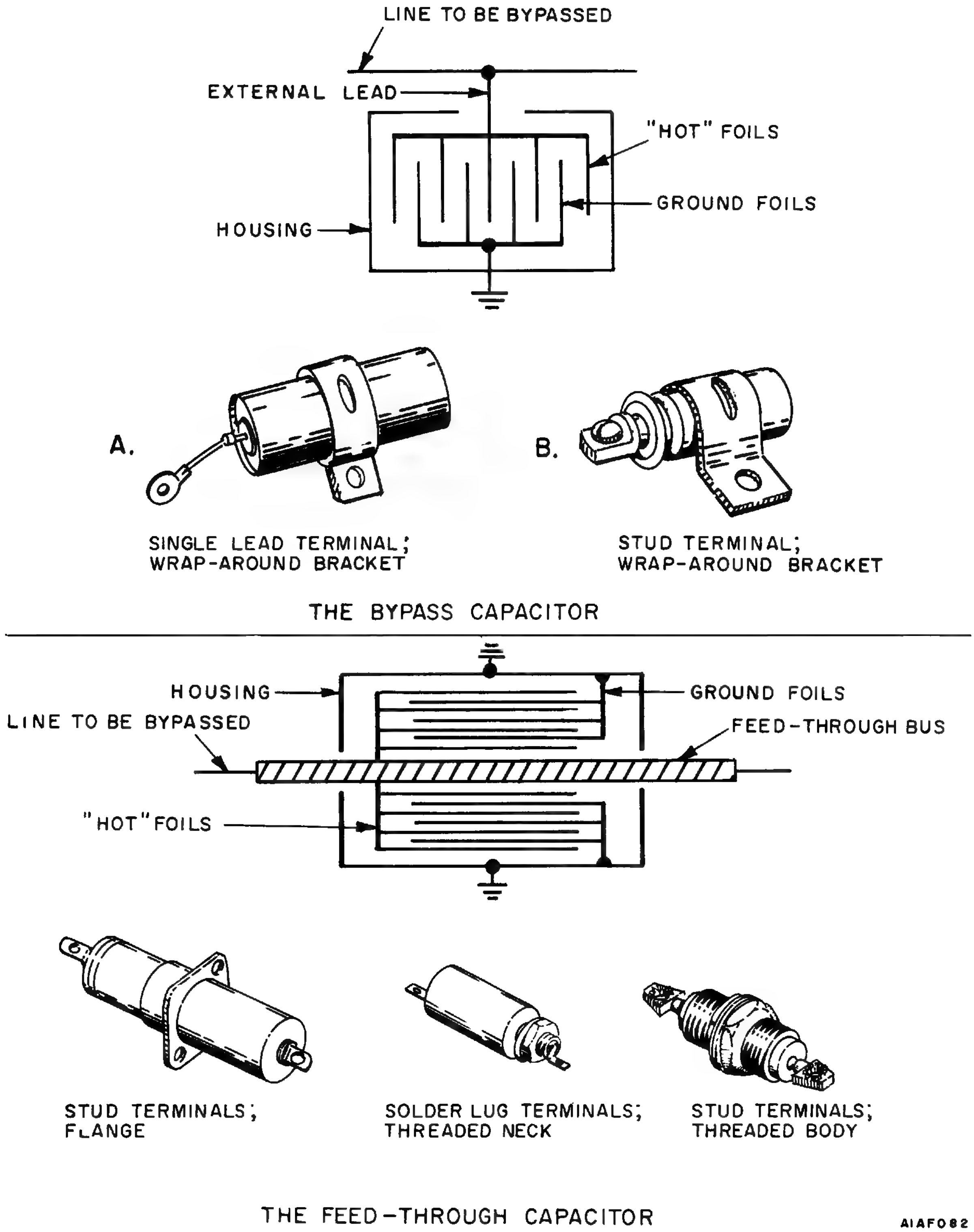


Figure 7 - 50. Suppression Capacitors

a. Applications

(1) Bypass capacitors are used in many applications because they are easily obtained, easily mounted, adaptable to many functions, and rugged. A disadvantage is that they are unable to bypass broadband noise.

(2) Wire lead bypass capacitors may be used to suppress interference in many different types of equipment including ignition systems, generators, DC motors, power lines, voltage regulators, fluorescent lamps, etc.

(3) Feedthrough capacitors are the best types available for general purpose applications because they are able to eliminate the highest frequency of transients ordinarily left unbypassed by other capacitors. Their chief disadvantage in field applications lies in the installation difficulties they present. Feedthrough capacitors may be used to suppress interference in DC motors, rotary inverters, dynamotors, ignition systems, and similar equipments. See figure 7-52.

(4) A power line that carries the relatively low-frequency alternating currents (50 to 400 hertz) required in most installations, may be cleared of undesired high-frequency transients with a capacitor. Capacitors control interference from a line by short-circuiting high-frequency signals that are present, while permitting the line current to pass on to the load. See figure 7-53.

(5) Used across switches, capacitors provide a means of reducing the generation of radiated emissions.

(a) The tendency for current-carrying switches to arc when opened may be minimized through the proper application of a capacitor. Tied across the contacts, either alone or in combination with a resistor or diode, capacitors will prevent arcing by providing a short circuit for the surge current that is present when a switch is opened. See figure 7-54.

(b) Capacitors can be used in this application in both AC and DC circuits. Choose the correct value of capacitance for the AC application to prevent pitting of contacts.

b. Installation Techniques. Two procedures to follow when installing capacitors intended for suppression applications are:

(1) Keep all lead lengths short.

(2) Secure brackets and threads to chassis ground, using the best means available to insure good electrical ground connections. The use of a tooth-type lockwasher that bites into a chassis may be used for such applications. It is noted that feedthrough capacitors must have the output shielded to prevent undesirable coupling with the input.

7.6.3 Filter Networks

A filter is a network that permits the transmission of signals at some frequencies and impedes their transmission at others. This is achieved by introducing a high impedance into the path of the undesired currents and then shunting them to ground through a low impedance. Although usually more effective than capacitors alone, filters, because of their bulk, should not be used as a field expedient if a capacitor will perform adequately as the suppressor. Filters are designed to affect the normal operation of power, control, or signal circuits as little as possible. By proper selection of the values of the elements, a filter may be made to attenuate almost any undesired frequency while passing others essential to the proper operation of equipment.

a. Classifications

Filters are generally classified in three ways:

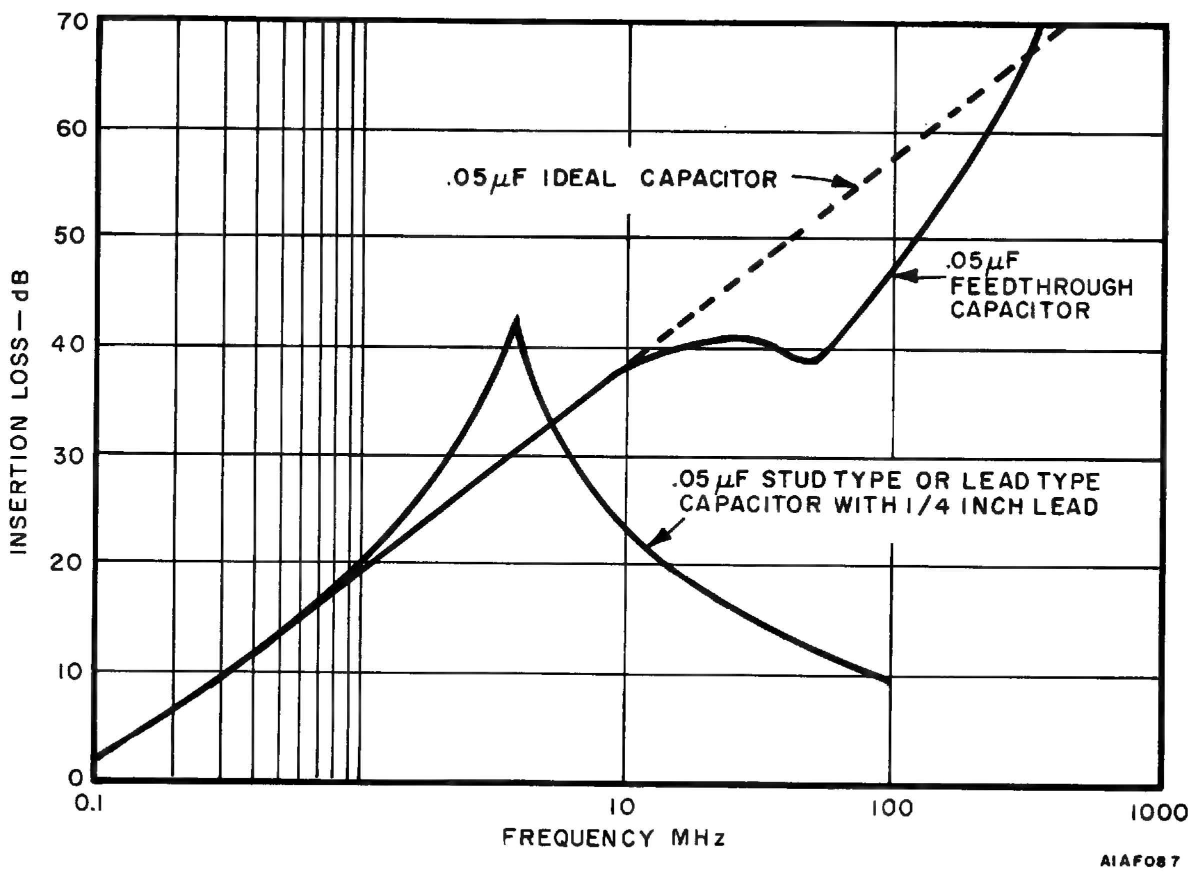


Figure 7 - 51. Comparison of Insertion Loss Characteristics for Typical Feedthrough With Lead-Type Capacitor of Same Value

(1) By the configurations they assume (figure 7-55)

L-type
T-type
Pi-type
Combinations of L-T-, and Pi-type.

(2) By the circuits in which they are used:

Power line
Harmonic suppression
Rectifier output.

(3) By the frequencies they pass:

o Low-pass filters. Band-pass filters pass low-frequency currents while attenuating high-frequency currents.

o High-pass filters. High-pass filters pass high-frequency currents while attenuating all low-frequency currents.

o Band-pass filters. Band-pass filters transmit frequencies within a certain region while attenuating all frequencies above and below that region. Band-pass filters are frequently used in intercommunication systems, in the input circuits, and in intermediate frequency (IF) circuits. They are used also in the output circuits of transmitters to suppress spurious radiations. A variation of the band-pass type is the bandstop filter which passes everything except a specific band of frequencies, which it attenuates. Band-pass filters are usually incorporated into equipment during manufacture.

The attenuation characteristics of the various filter types are shown in figure 7-56.

Attenuation, insertion loss, and frequency range of attenuation are the primary characteristics that determine filter suitablity for emission control. If a selected filter does not provide the minimum attenuation required for the stop-band, it is not satisfactory, regardless of its other characteristics. The attenuation of a filter is expressed as the ratio of the filter input voltage to the filter output voltage, measured under normal circuit conditions:

$$\text{Attenuation (dB)} = 20 \log \frac{E_1}{E_2}$$

where:

E_1 = voltage across filter input terminals
E_2 = voltage across filter output terminals

The attenuation figure, however, does not take into consideration the source and load impedances and, therefore, does not represent a true indication of the suppression effectiveness of a filter. The insertion loss criterion is a far more realistic measure of a filter's effectiveness, as it is a function of both source and load impedances as well as a function of the filter network itself.

In their catalogs, most filter manufacturers quote values of insertion loss (the ratio of voltages at a given frequency appearing across the load terminals before and after the filter is inserted into a circuit):

$$\text{Insertion loss (dB)} = 20 \log \frac{E_3}{E_2}$$

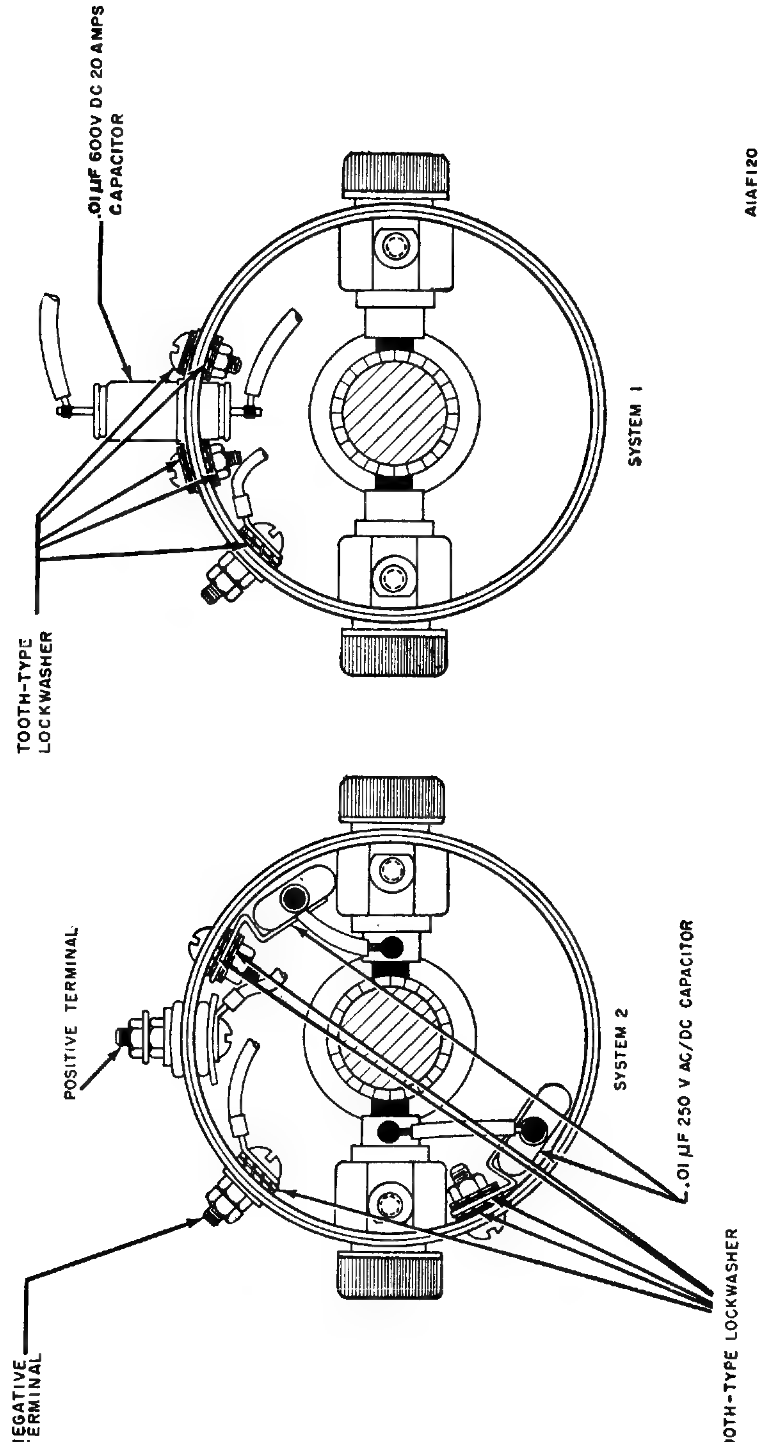


Figure 7 - 52. System 1: Installation of Feedthrough Capacitor Mounted at Positive Terminal in DC Motor
System 2: Alternate Installation of Bypass Capacitors Mounted at Brushes

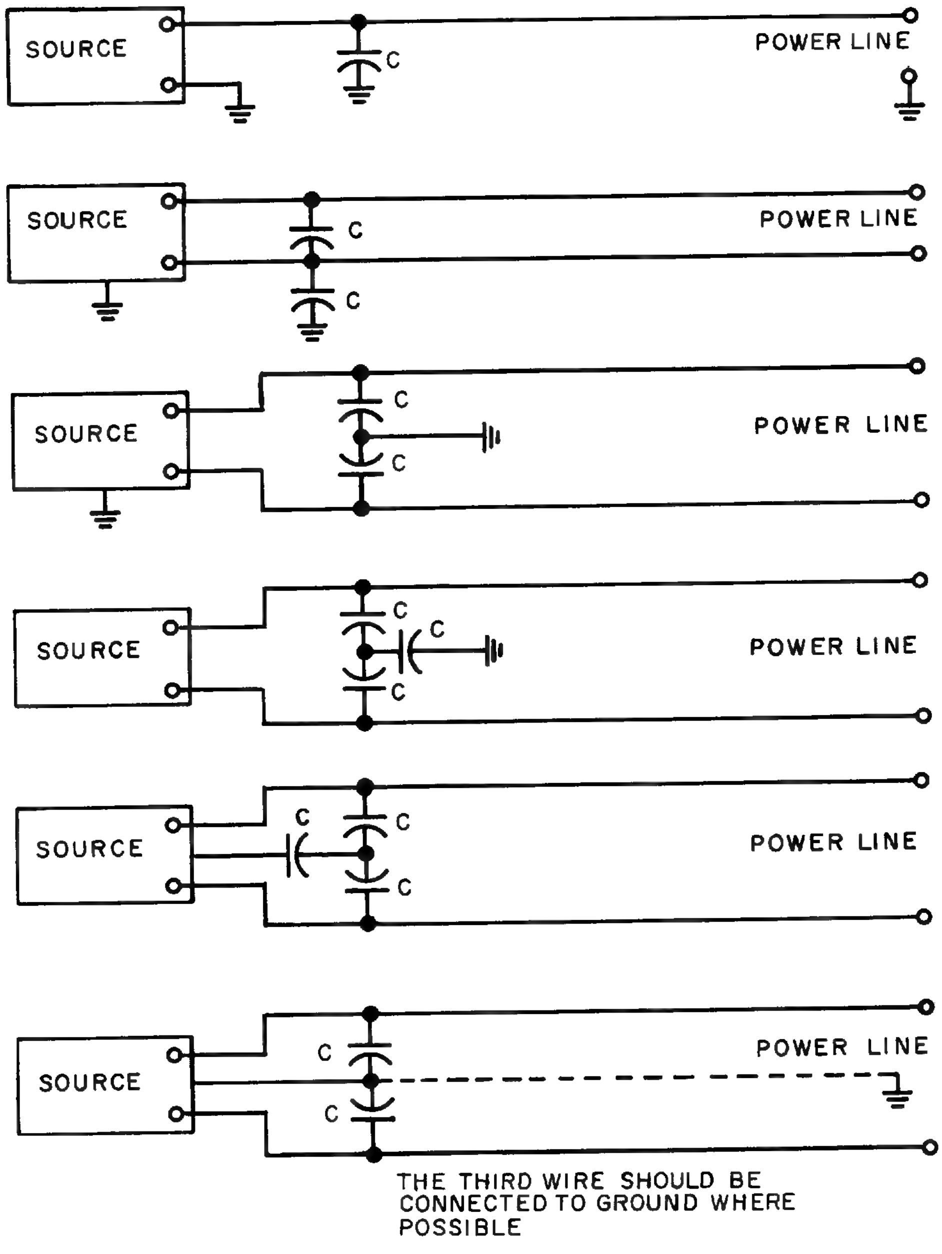
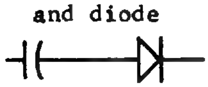
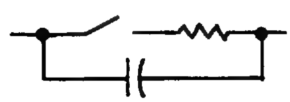
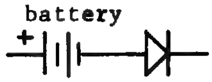
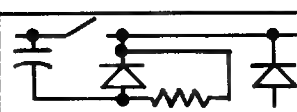
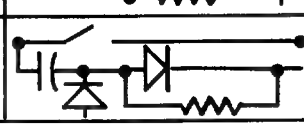


Figure 7 - 53. Bypass Capacitors Used to Filter Grounded and Ungrounded Power Lines that Supply Grounded and Ungrounded Equipment

Components	Placement	Requirements 1 Retard Build up of Gap voltage	Requirements 2 Limit Peak of Gap Voltage	Requirements 3 Minimize Sharp Wave Front Transients
Capacitor	Load	G	A[c]	P
	Switch	G	A[c]	P
Linear resistor	Load	P	A[d]	A
	Switch	P	A[d]	G
Semiconductor diode	Load	P	G	A[b]
	Switch [a]	P	G	
Back-to-back diodes	Load	P	G	A[b]
	Switch [a]	P	G	A[b]
Capacitor and diode 	Load	Capacitor is superfluous		
	Switch	G	A[c]	G
Series R shunt C		A[d]	A[c]	G
Coupled secondary		P	G[d]	A
Diode and battery 	Load	P	G	A[b]
	Switch	P	G	G
Composite circuit		G	G	A
Composite circuit		G	G	G

LEGEND
G = Good
A = Intermediate
P = Poor

NOTES

a = Diode must have knee at voltage greater than that of supply

b = Determined by inherent shunt capacitance of diode

c = Capacitance must be sufficiently large

d = Resistance must be sufficiently small

Figure 7 - 54. Switch Suppression Methods

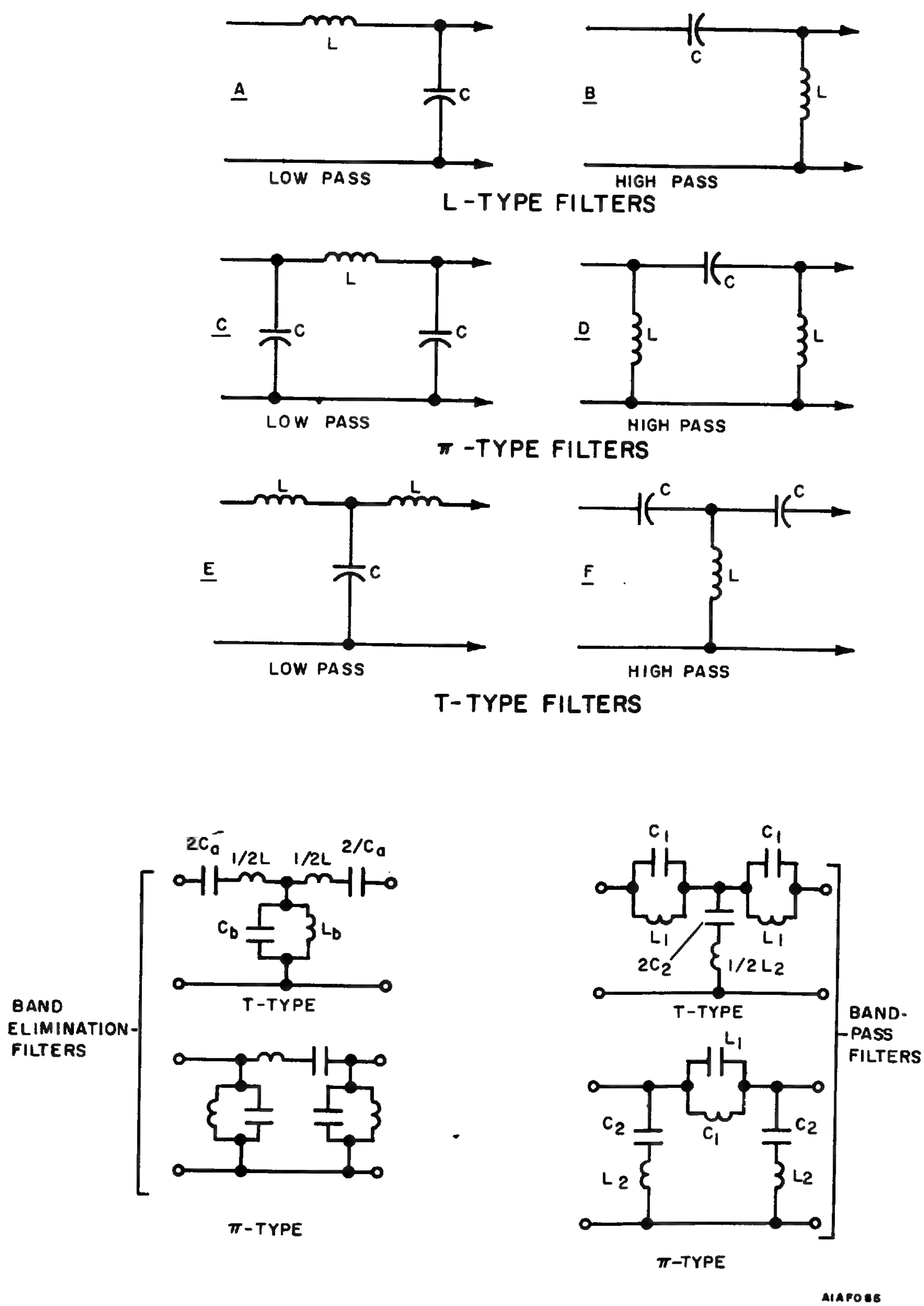


Figure 7 - 55. Filter Types

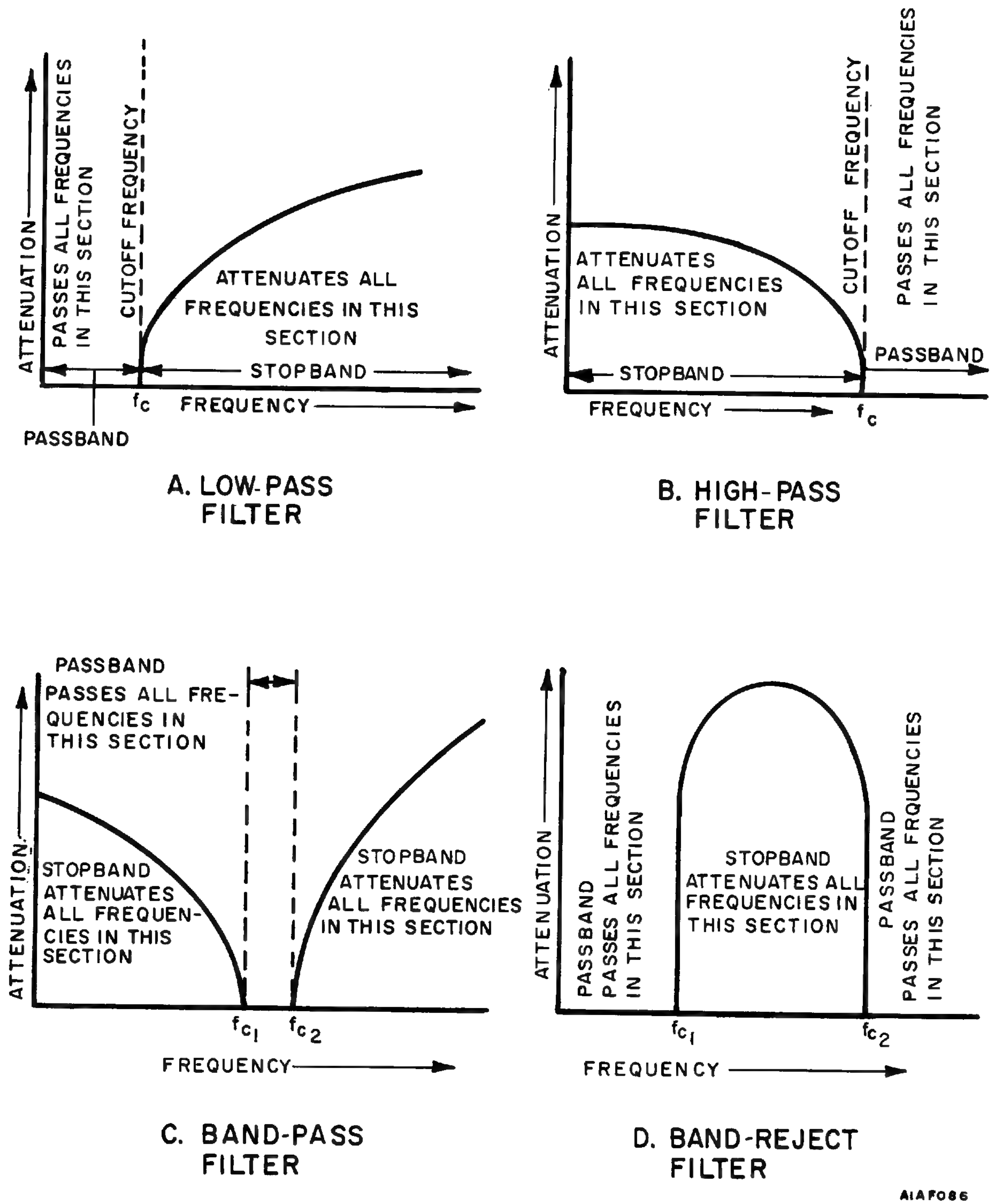


Figure 7-56. Filter Attenuation Characteristics

where:

E_2 = load voltage with the filter in the circuit
E_3 = load voltage without the filter in the circuit

However, the insertion loss is usually quoted by the manufacturers for a 50-ohm system. If the circuit to be filtered does not have both a 50-ohm input and output impedance, as will be the case in most installations, the insertion loss will differ from the catalog value. MIL-STD-220 specifies procedures for the measurement of insertion loss in a 50-ohm system. Other procedures are described in the referenced IEEE-GEMC Symposium documents for measuring insertion losses in other than 50-ohm systems, and under "worst-case" resonance conditions.

b. Applications

(1) Simple Filters. Simple filters, sometimes called brute force filters, are used as low-pass power-line filters where appreciable filter selectivity is not required. The selection of the configuration to use depends on the equipment to be suppressed and the amount of suppression required.

Applications of L, Pi, or T filters for use in power lines are shown in figure 7-57. Power-line filters as a class of filters are generally of the low-pass variety. Low-pass filters are usually applied at either the output of interference sources, or at the input of the associated load.

Low-pass filters intended primarily for filtering high-frequency noise currents from low-frequency AC power leads are also used for DC applications. These filters have a low insertion loss at power frequencies and DC, but a high insertion loss for higher frequencies. Low-pass filters are in use primarily to prevent conducted interference from entering a sensitive receiver through the AC or DC supplies feeding it.

(2) Complex Filters. In simple power-line filters, only one frequency is of importance in the pass band. To obtain optimum effectiveness over a selected range of frequencies, more complex filters are required. Such filters are called m-derived composite filters. For frequencies above 70 or 80 MHz, sections of coaxial transmission lines are used as filter elements to simulate the required values of lumped capacitance and inductance.

(3) Harmonic Suppression Filters. These filters are used at the output of transmitters to prevent any harmonic of the desired transmitter frequency from reaching the antenna. They are usually band-pass filters and are inserted in the output of the transmission line feeding the antenna, or between the transmitter and the antenna. In the pass band, the filter must perform electrically as though it were a section of the transmission line cable into which it is inserted. When great attenuation is desired, it is better to use two or more filters in series than to use one complete filter. For ultra-high frequency (UHF) use, short sections of transmission line are used as filter elements. Harmonic suppression filters are usually incorporated into equipments during the equipment design.

c. Installation Techniques. When using filters, proper installation is absolutely necessary to achieve good results. Effective separation of input and output wiring is mandatory, particularly for good high-frequency performance, because the radiation from wires carrying potential interference signals can couple directly to output wiring, thus circumventing and nullifying the effects of shielding and filtering. Input and output terminal isolation is most easily accomplished by using a filter that mounts through a bulkhead or chassis. In all cases where bulkhead mounting isolation is not feasible, isolation by shielded wiring is mandatory. It is highly desirable to locate suppression components in or on the device generating the unwanted emission. The RF impedance between filter case and ground must be as low as possible. The methods of mounting a filter become very critical at high frequencies. If complete isolation is effected between input and output, filter insertion loss will approach the design figure. See figure 7-58 for correct mounting techniques.

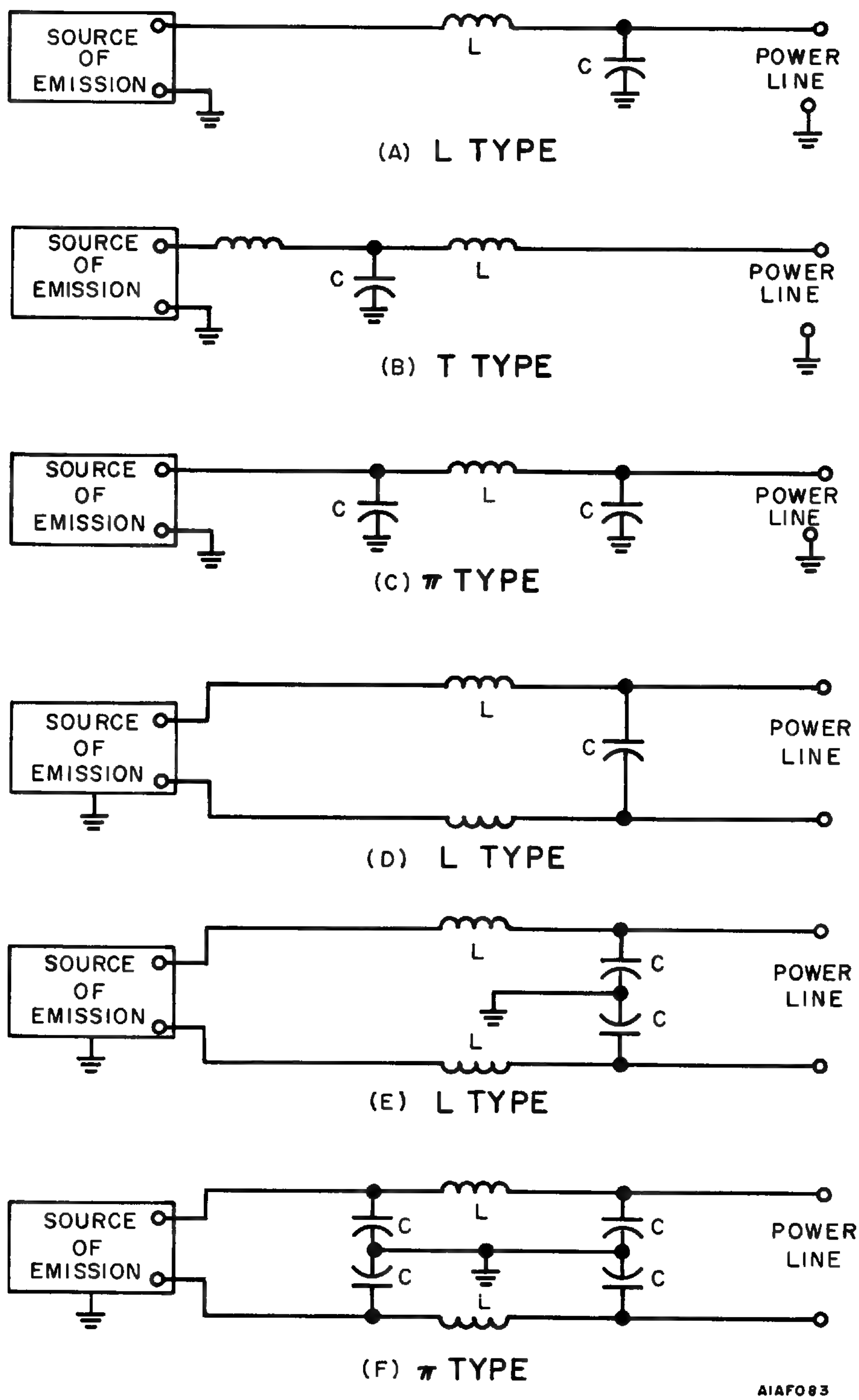


Figure 7 - 57. Applications of L, Pi, and T-Type Filters

The following installation procedures should be observed:

(1) A filter should be shielded with the output leads isolated from the input leads.

(2) Metal-to-metal contact must be made between the metal cover and all mounting surfaces of the shielded enclosure.

(3) The size of the filter terminals should be sufficient to carry the required current.

(4) There should be low-impedance between the filter unit and the source to permit free flow of the bypassed currents.

(5) Short leads should be used with capacitors.

(6) The filter should always be mounted as close as possible to the filtered equipment with shielded leads used as the coupling medium.

(7) All leads should be run close to the ground planes and in opposite directions to avoid coupling between the leads. Never loop them.

(8) The latest Navy-approved filters and requirements in MIL-F-15733 shall be met where applicable.

(9) Both the filter and equipment must be well grounded through low radio-frequency impedances. They should have metal-to-metal contacts at all mounting surfaces and short grounding straps. Ground surfaces should be cleaned as thoroughly as possible when the installation is being made.

(10) When mounting the filter in a box, insure that the cover and box are thoroughly bonded together by a clean metal-to-metal contact. This isolates the input and output circuits to each end of the filter, thereby reducing to a minimum the coupling across the filter.

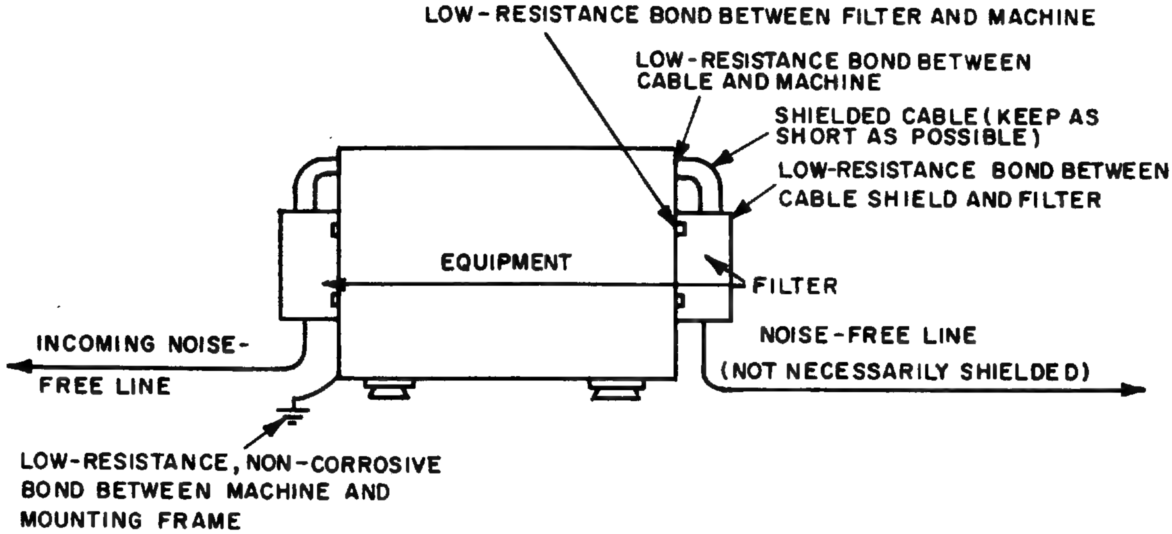
(11) AN type connectors should be used on hermetically sealed filter units in place of an external filter box.

(12) The low-impedance path which was made in placing the filter into the box must be continued in the installation of the filter box to the equipment. The location of the filter must be such that a low-impedance path back to the ground plane of the equipment is maintained for any current flowing through the capacitors of the filter. Three methods of grounding the filter box with respect to the RF ground connection required are: welding, bolting, and the use of ground straps. In mounting the filter, use a bulkhead, chassis, or equipment case as an isolating shield between the input and output of the filter.

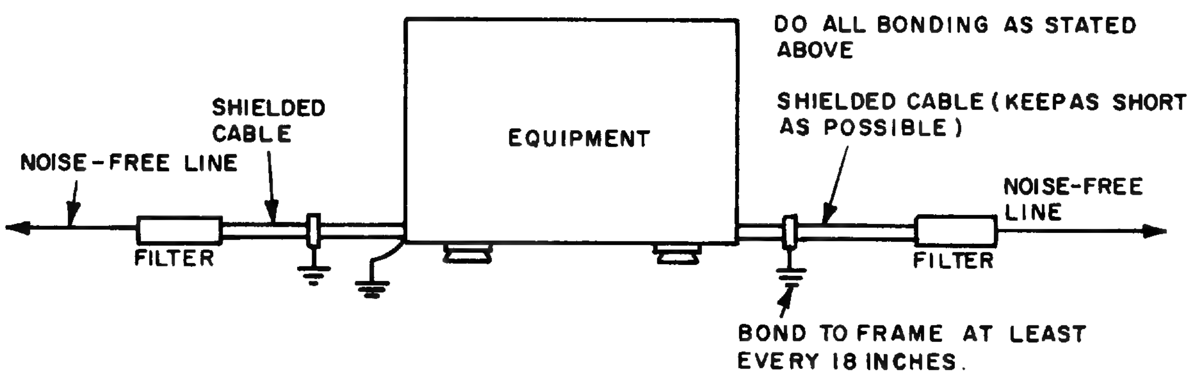
(13) If a filter is used in the antenna to filter unwanted pick-up, it will often be necessary to add more shielding to the cable between the filter and the equipment. Pick-up is not always caused by inadequate cable shielding or inadequate filtering. In many cases, poor grounding of the cable shield at the filter and at the equipment is the fault.

(14) A simple capacitor filter is preferred to the more complicated network filters (lattice and ladder) if it provides the required degree of attenuation.

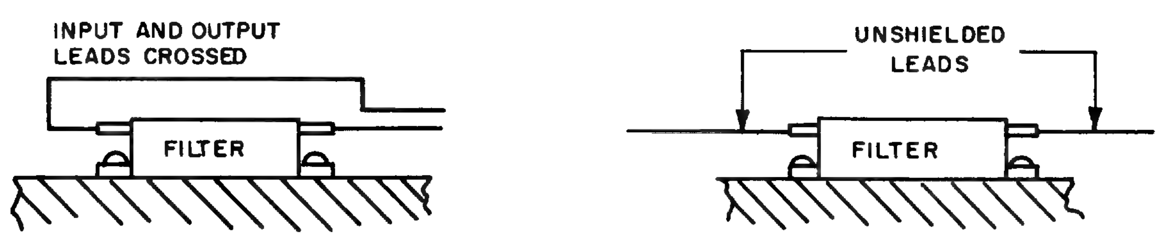
(15) The filter should be located at the emission source somewhere along the cabling between the source and receiver or at the input to the receiver. The location of the filters is determined by the coupling of the undesired signal to the receiver.



(a) PREFERRED INSTALLATION-FILTERS MOUNTED DIRECTLY ON EQUIPMENT



(b) ACCEPTABLE INSTALLATION-FILTERS NEAR EQUIPMENT ON THE SAME GROUND PLANE



(c) UNACCEPTABLE INSTALLATIONS

Figure 7 - 58. Filter Installations

7.6.4 Trade-off Factors

When designing or selecting a filter, a number of parameters must be considered.

a. Impedance Matching. The elements of the filter must be chosen so that the impedance network matches the line into which it is inserted. This is especially true of transmission lines so that the filter does not impair the normal function of the equipment at both ends of this line.

b. Voltage Rating. Consider the voltage rating on the filter used on power lines, and the limits within which electrical power subsystems are to operate. Under some conditions the voltage may deviate by a large amount from the normal line voltage. The filter voltage ratings must be sufficient to provide reliable operation under extreme conditions.

c. Voltage Drop. Determine the maximum allowable drop through the filter and design accordingly. Ensure that the voltage drop caused by a filter does not exceed the total drop permitted by the installation and equipment operating criteria.

d. Current Rating. Current rating should be for the maximum allowable continuous operation of the filter. Calculate the current rating for filter elements, such as capacitors, inductors, and resistors. Whenever possible, the current rating of filters should be consistent with the current rating of the wire, circuit breakers, or fuse with which the filter will be used. A filter with a higher current rating than the circuit in which it is installed will often add to the weight and space penalty. A filter with a lower rating is a safety hazard. The safety factor used in rating filters should also be consistent with those used for other circuit components.

e. Frequency. Consider both the operating frequency of the circuit and the frequency to be filtered (attenuated). In general, do not use sharp filters to reject the power frequencies. If such a filter is required, its rejection characteristic must be wide enough to provide adequate attenuation over the power frequency deviation specified in the installation specification.

f. Insulation Resistance. The insulation resistance of the filter may vary during the life of the filter. Determine the maximum allowable variation of this resistance for proper filter operation.

g. Electrolytic Capacitors. Electrolytic capacitors are sometimes used in low-pass filters. The dissipation factor increases, and the capacitance decreases with age on the wet-type electrolytic capacitor. An RF bypass capacitor should be placed across the output of DC supplies to filter out any HF interference which may be present. The high dissipation factor or series resistance within the wet electrolytic capacitor makes it a poor filter for RF. If space is at a premium and the working voltage of the circuit is low, a solid type tantalum capacitor with a low-dissipation factor may be used.

h. Ground Leads. Ground leads on capacitors and filter enclosures should be as short as possible. Capacitors having metal cases with grounding studs or mounting clamps provide leadless grounds. Feedthrough capacitors and filters are grounded through the metal case and mounting flange.

i. Size and Weight. Size and weight can be the deciding factor in some filter applications. When space is at a premium, adding or subtracting various filter elements may reduce the size and weight of the filter.

j. Isolating and Shielding. Isolating and shielding is the key to good filtering. A filter network may be placed in a shielded enclosure or metal case and grounded accordingly.

k. Transmission Line Filters. These filters are completely shielded in a case and are usually terminated with an input and output coaxial connector.

l. Filters in Connector Contacts. Miniature filters can be constructed into a single-pin contact and placed in a multipin connector receptacle. This connector consists of a group of low-pass filters for the isolation and suppression of RF.

7.7 CONTROL OF EMR HAZARDS

7.7.1 General

Other portions of this handbook discuss potential EMR hazards to personnel, flammable materials, ordnance and electronic hardware, including prediction and measurement techniques. The potentially serious nature of EMR hazards requires the most scrupulous observance of precautions. Positive efforts must be taken to minimize or reduce potential hazards without a reduction in operational requirements. Adequate indoctrination and training in EMR hazard precautions are essential for all personnel engaged in installation design, as well as equipment operation, maintenance and test. It is particularly important that Navy personnel be aware of their specific responsibilities with regard to the execution of safety and protective measures. In addition, rigid control must be exercised to ensure that proper instructions, protective equipments, warning signs and alarms, and other control methods are available to, and utilized by, all involved personnel.

While every effort must be made to protect personnel and materials from exposure to hazardous levels of EMR, it is neither necessary nor desirable to impose restrictions on antenna radiations, Such actions tend to restrict operations, maintenance, and test procedures which could otherwise be carried out in safety, providing adequate precautions are employed.

The following general precautions are to be employed to preclude the potential hazards:

a. Where test procedures require free space radiation, the radiating antenna will be so positioned as to avoid directing the energy beam toward inhabited structures or other personnel groupings, fueling, ordnance, and electronic material handling areas. In the positioning of such radiating antennas, care will be taken to avoid reflecting either the primary beam or associated side lobes in such a manner as to create potential hazards.

b. Aircraft employing high-power radars, vans and other vehicles containing radiating antennas shall be parked, or have their antennas oriented, so that if an equipment is energized, the resultant beam is directed away (or into absorbent chambers) from personnel working areas, fueling areas and electronic equipment and ordnance storage handling and operating areas.

c. Where feasible, all transmitting antennas, i.e., fixed, as well as those on mobile vans and associated with transportable and portable equipments, should be located to minimize exposures in areas adjacent to, or in the installation.

d. All rotating antennas should radiate only when rotating. If necessary, further restrictions can be imposed, such as sector blanking (i.e., installation of cutout devices in the electrical or mechanical components of a system to automatically end transmission when the antenna is pointed in a predetermined direction) or by instructing operating personnel not to transmit in certain azimuths and/or elevations.

e. All non-rotating antennas should be trained and elevated away from inhabited areas, fueling systems, and/or ordnance and electronic equipment operating, storage and handling areas.

f. Appropriate standard radiation hazard warning signs should be available and posted to designate potentially hazardous areas. These signs are described in subsequent portions of this section.

g. Care should be taken so that laser beams are not directed towards personnel, flammable materials, electronic hardware or ordnance.

h. In situations where operations would be unduly restricted by implementation of the above methods, and those described in subsequent paragraphs, suitable attenuation of power density levels may be accomplished by shielding (see section 7.5).

7.7.2 Control Hazards to Personnel

As noted in earlier portions of this handbook, hazards to personnel can result from several causes, i.e., direct exposure to EMR, X-rays inadvertently produced in electronic equipment, and shocks and burns caused by RF potentials induced in various metallic objects that may be contacted by personnel and exposure to laser radiation. The following paragraphs outline precautionary measures which can be employed to minimize or eliminate these hazards to personnel which may result in both direct and indirect injuries.

a. EMR. All areas in which the power density is predicted or measured to be above $10mW/cm^2$ should be considered potentially hazardous areas and are subject to the following precautionary measures:

(1) All such areas shall be appropriately posted with the standard warning sign shown in figure 7-59. Personnel should not be permitted in these areas except under emergency conditions. Where the possibility of accidental exposure still exists, a man should be stationed within view of the transmitting antenna and in communication with the radar operator while the antenna is radiating.

(2) Personnel frequently exposed to EMR in connection with their regular duties are subject to the periodic medical examinations in accordance with NCPI 792.11 or NAVMED P-5055, as applicable.

(3) People with metallic implants or medical electronic devices,such as pacemakers, in their body should be extremely careful and perhaps excluded from working in or visiting areas of EMR, because of the susceptability of the devices.

(4) The practice of discharging, under test, the RF output of high power generators which generate average power levels of 10 mW/cm^2 or more, into the surrounding area, is discouraged. Dummy loads, water loads, or other absorptive materials may be used to absorb the energy output of such equipment while being operated or tested.

(5) Visual inspection of feedhorns, open ends of waveguides, and any opening emitting electromagnetic energy will not be made unless the equipment is definitely secured for the purpose of such an inspection.

(6) When operating or servicing radar or high power radiating systems, operating and maintenance personnel shall observe all radiation hazard signs posted in control and operating areas to ensure that the equipments are operating in such a manner that personnel are not subjected to hazardous energy levels.

(7) If, while working in a previously declared safe area, heat is felt coming from the direction of a radar antenna, the area should be evacuated until it can be verified that the heat did not come from the radar beam.

(8) Photographic personnel should be cautioned about the dangers associated with exploding flashbulbs in the main beam of radars, even at considerable distances from the antenna, as severe cuts and burns can occur. Flashbulbs may be safely stored in copper-sheet lined boxes which will shield them from EMR. When using flashbulbs in the vicinity of radars, they should be left in their cartons until used and should be handled with gloves.

(9) Minimum safe distances from radar antennas shall be maintained by all personnel. The minimum safe distance from specific radar antennas and the maximum exposure times within these distances under certain modes of operation are listed in NAVWEPS 16-1-529 and NAVSHIPS 0900-005-8000. Some minimum distances are presented in Table 7-11.

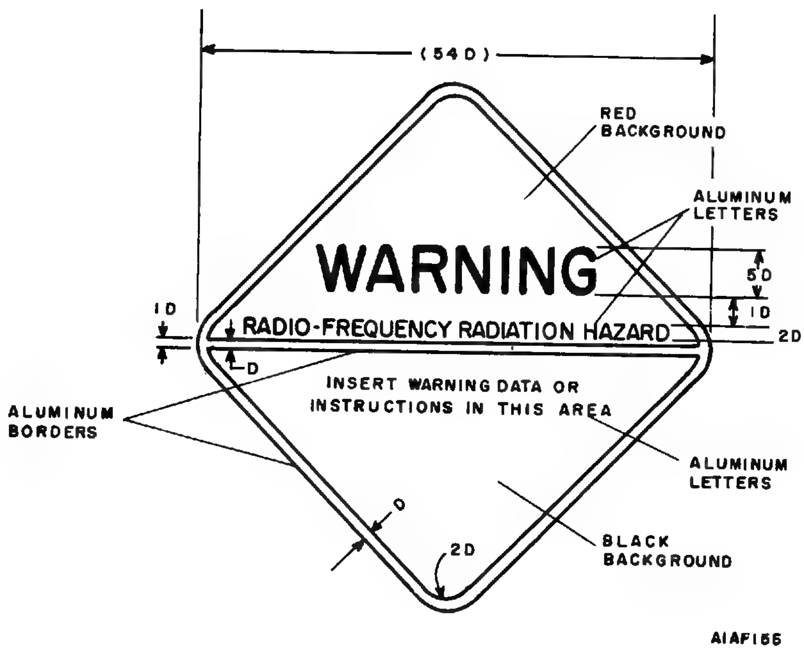


Figure 7 - 59. RF Radiation Hazards Warning Sign

Table 7-11. Distances to 10 mW/cm^2 Point on the Major Lobe of the Radiating Antenna of Radar Sets (Fixed Beam)

RADAR SETS	ANTENNA DIMENSIONS (Ft.)	DISTANCE TO 10 mW/cm^2 (Ft.)
AN/CPN-18	W - 7	182
AN/CPN-18A	H - 9	182
AN/CPS-9	D - 7¾	180
AN/FPN-40		
Azimuth Antenna	H - 3	92
	W - 9	
Elevation Antenna	H - 10	80
	W - 2.5	
AN/FPS-3A		170
AN / FPS-4	H - 3	188
AN/GPS-4		105
AN/MPM-1		30
AN/MPN-11		95
AN/MPQ-21 (10 ft.) antenna dimension		300
AN/MPQ-21 (7 ft.) antenna dimension		210
AN/MPQ-18		175
AN/MPQ-14		45
AN/MPQ-10 S		50
AN/MPQ-10 B		45
AN/MPS-23		530
AN/MPS-22		185
AN/MPS-21		430
AN/MPS-16		50
AN/MPS-14		475
AN/MPS-12		175
AN/MPS-11		100
AN/MPS-10 C		105
AN/MPS-8		105
AN/MPS-7		175
AN/MPS-4		205
AN/PPS-4		2
AN/TPS-1 CD	H - 10	188
AN/FPS-6	H - 30	380
AN/FPS-6A	H - 30	380
AM/MPS-14	H - 30	380
AN/FPS-18	H - 11	400
	W - 17.5	410
AN/FPS-16 (1 MW)	D - 12	400
AN/FPS-16		530
AN/FPS-71	H - 11	280
	W - 40	
AN/MPQ-10	D - 5.7	37
AN/MPQ-10A	D -	
AN/MPQ-12	D - 6	56.5
AN/MPQ-29	D 2.5	21.5
AN/TPS-16	H - 4	33
AN/TPS-1D	W - 15	33
AN/TPS-25	H - 1.67	40
	W- 2.24	40

Table 7-11. Distances to 10 mW/cm^2 Point on the Major Lobe of the Radiating Antenna of Radar Sets (Fixed Beam) (Continued)

RADAR SETS	ANTENNA DIMENSIONS (Ft.)	DISTANCE TO 10 mW/cm^2 (Ft.)
AJAX acquisition radar	H - 4.4	176
	W - 15.8	176
AJAX missile tracking radar	D - 5.9	97
HAWK continuous acquisition radar	H - 1.58	67
	W - 7.58	67
HAWK high power Illuminator	D - 4.0	356
HAWK low power illuminator	D - 4.0	105
HAWK pulsé acquisition radar	H - 5.17	55
	W - 22.0	
HAWK range only radar	D - 4.0	148
NIKE-HERCULES acquisition radar	H - 4.4	127
	W - 15.8	
Improved NIKE-HERCULES acquisition radar (HIPAR)	H - 20.8	240
	W - 43.0	
NIKE-HERCULES missile tracking radar (Ajax mode Basic & improved)	D - 7.7	126
Improved NIKE-HERCULES target tracking radar (wide pulse)	D - 7.7	230

(10) It is recognized that during the performance of certain functions, Naval personnel may be required, at times, to enter or pass through hazardous areas. Accordingly, the Navy has developed protective devices for such instances which provide coverage and shielding primarily by reflection of the incident energy. A discussion of two such devices follows.

(a) Protective Suit. A protective suit made from metalized heavy duty nylon. The suit contains special features to maintain complete electrical continuity and prevent leakages at interfaces. The suit requires the wearing of an overgarment, such as rubber boots, gloves and coveralls to prevent arcing in the presence of fields exceeding 150 mW/cm^2 and may be used in the presence of fields between 200 and 10,000 MHz.

(b) Safety Goggles. Safety goggles were developed primarily for use in radar research and may be used over a limited frequency range for eye protection. They are similar to welders' safety goggles and possess lenses having either a metallic film coating or containing a micromesh screen. The goggles are lined with commercially available RF absorbing material, with the exterior coated with a conductive paint designed to reflect the energy.

(c) X-Ray Radiation from Electronic Equipment. As noted in other portions of this handbook, when high velocity electron beams strike metals and certain materials, X-rays are produced which may be hazardous to personnel, especially if the shielding incorporated into the equipment design is not intact. The X-rays produced by accelerating potentials in the order of 15,000 volts are not hazardous beyond approximately a foot from the source and therefore do not require elaborate additional shielding to make the device safe for nearby personnel. However, as the potentials become greater than 15,000 volts, the X-rays have greater energy and therefore require additional shielding. When installing or performing preventive or corrective maintenance on electronic devices that produce X-ray radiation as an undesirable by-product, the following precautions should be observed inasmuch as' the required maintenance will usually entail disassembling the microwave generating elements and disturbing the integrity of the shielding.

o Personnel should not linger near any equipment on which the equipment covers have been removed.

o Observe all warning signs on the equipment and all written safety precautions in the instruction manuals for the equipment that deals with X-ray hazards. (See figure 7-60.)

o Do not use jumper interlocks that permit the servicing of operating equipment with the protective X-ray shielding removed, unless such procedures are called for in the instruction manuals.

o Be sure to replace all protective X-ray shielding when servicing is complete, so that operating personnel or others will not unknowingly be subjected to harmful X-ray radiation.

o When bench testing X-ray producing electronic devices be sure that adequate X-ray shielding is provided to protect all personnel in the testing area.

o Determine the latest safety precautions to be observed by maintenance personnel, including the use of the latest approved dosimeters by consulting the installation's industrial hygienist.

b. Lasers. Hazards associated with laser installations and devices are detailed in NAVMED P5052-35. Safety precautions contained in the latest issue of the aforementioned document shall be followed. Some of those safety measures are summarized below for information. In addition, a medical surveillance program shall be established for those individuals whose assignment may result in exposure to laser radiation. Details of the surveillance program are also contained in NAVMED P5052-35.

LETTERING TO BE BLACK

BACKGROUND TO BE YELLOW

SYMBOL TO BE PURPLE (MAGENTA)

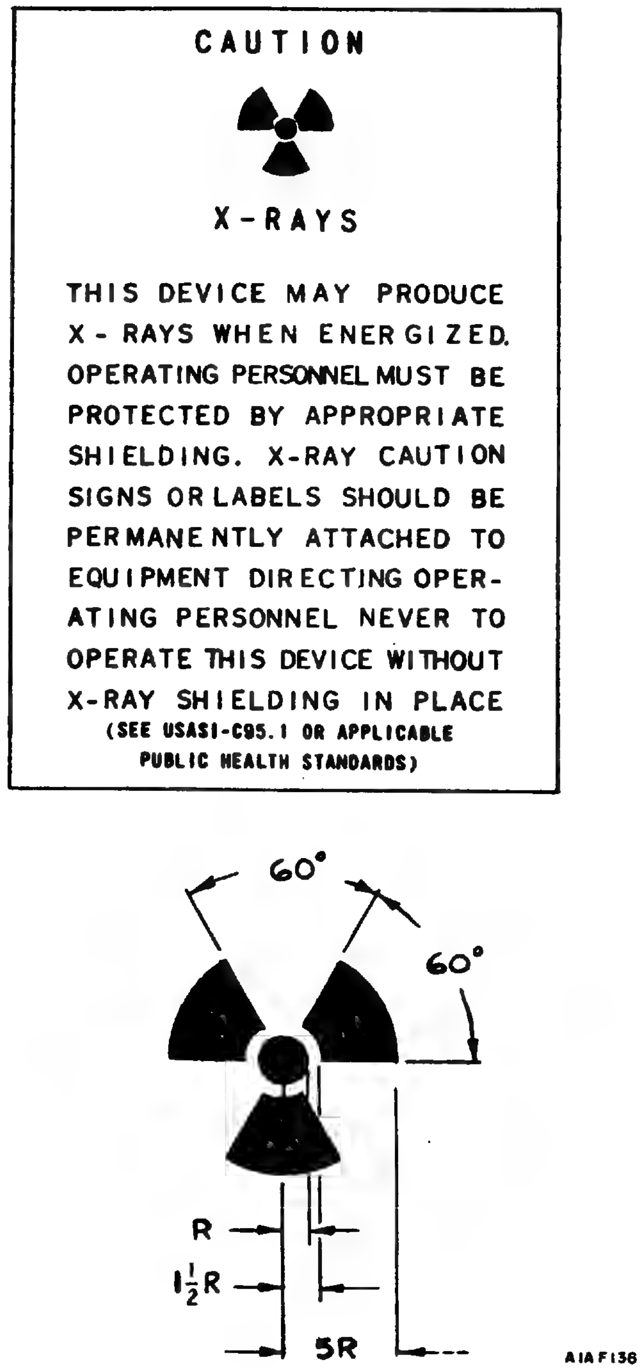


Figure 7 - 60. X - Ray Radiation Caution Label

(1) Laser Installations

(a) Wherever feasible laser equipment should be located in a room separated from general laboratory areas or contained in a light-proof enclosure. Laser with power outputs (mega and gigawatt range) exceeding the capabilities of protective devices shall be housed in an area to which personnel will not be allowed access during operation.

(b) Laser spaces shall be free of reflective surfaces or objects, particularly in the target area.

(c) Work with lasers shall be done in areas of high general illumination, except where accomplishment of a mission would be impaired.

(d) A warning sign or signs such as that of figure 7-61 shall be permanently posted at all entrances of the laser enclosure.

(e) Pulsed and CW laser installations with reflected intensities exceeding the maximum allowable safe levels shall:

o Have safety interlocks at entrances of the laser space such that unauthorized or transient personnel are denied access while the laser power supply is charged and capable of firing. When interlocks are actuated, a fail-safe circuit shall de-energize the laser system within 5 seconds.

o Have an alarm system including an audible signal and flashing lights (visible through laser safety eyewear) which are actuated when the laser power source is being energized (e.g., capacitor banks begin to charge, CW laser power supply is energized, before laser tube is switched on, or chemical pump energy source is energized).

o Be free of extraneous reflective surfaces or objects particularly in the target area. Walls and ceilings should be painted with a diffuse nongloss paint, preferably black, near the target area and a light color elsewhere to increase ambient illumination.

o Have adequate ventilation where inert liquified coolant or toxic gases are used in the system.

o Have a master electrical power shut-off outside the laser enclosure.

(2) Laser Equipment

(a) Electrical and electronic circuits associated with laser apparatus are to be installed in accordance with the applicable requirements of NAVMAT P-5100 and Requirement 1 of MIL-STD-454, Standard General Requirements for Electronic Equipment.

(b) Firing systems will be designed with fail-safe controls in order to prevent the possibility of firing the laser accidentally.

(c) Laser equipment components that can produce extraneous direct, deflected or reflected radiation of harmful visible, ultraviolet, or infra-red light; X-ray or radio-frequency energy will be shielded. Flash lamps, rotating parts, capacitor banks, and other components that can fail and thereby produce hazardous flying pieces will also be shielded.

(d) A suitable fire-resistant low-reflective material will be provided as a backstop for the beam of carbon dioxide-nitrogen gas lasers.

(e) Safety precautions and safe operating procedures shall be posted in accordance with NAVMAT P-5100.

(f) Systems employing liquid nitrogen as a coolant shall comply with NAVWEPS OP-3199 publication.

(3) Operating Precautions

(a) Wherever possible, aligning the laser beam with the naked eye must be avoided and looking into the primary beam or its reflections is prohibited.

(b) Highly portable lasers shall be turned on only after an alignment check.

(c) The beam shall be discharged into a non-reflective and fire-resistant background. All extraneous reflective objects in path of beam shall be removed.

(d) Laser equipment shall never be left unattended while energized and shall be discharged when shut down.

(e) The countdown procedure shall be employed when firing pulsed and CW laser having reflected intensities exceeding the maximum allowable safe levels.

(f) The operation, maintenance, and repair of laser electrical and electronic circuits shall be performed in accordance with the applicable parts of NAVMAT P-5100.

(4) Personnel Precautions

(a) During the firing of a laser, personnel shall wear protective eyewear in accordance with the criteria of NAVMED P-5052-35. Lenses shall be marked to show the optical density and wavelength for which they are intended to provide protection.

(b) Those in charge of laser facilities shall be competent in laser technology and operation. All personnel assigned to work with lasers shall be fully instructed with respect to the hazards involved, safety precautions, and the use of safety devices.

(c) Only authorized personnel shall be permitted to set up, adjust, or operate laser equipment.

(d) When working on electrical and electronic components of laser equipment, personnel shall observe the safety precautions and use the protective clothing and devices.

(e) When working on liquified nitrogen cooling systems or when handling the liquified nitrogen, personnel shall observe the safety precautions and use the protective clothing and devices stipulated in NAVWEPS OP-3199.

(5) Field Precautions. The environmental and operational controls which are practicable in the laboratory, of necessity, may not be feasible under field conditions. However, the precautions listed above and those following should be enforced in laser exercises in the field wherever practicable:

(a) The laser should be treated as an ordnance piece, and laser operation and test should be confined to gunnery or missile ranges or other sites where similar security and safety measures are in force.

(b) Personnel should be excluded from the beam path to a distance where the energy is within permissible levels. This may be accomplished by the use of physical barriers, administrative control, interlocks, or by limiting beam traverse.

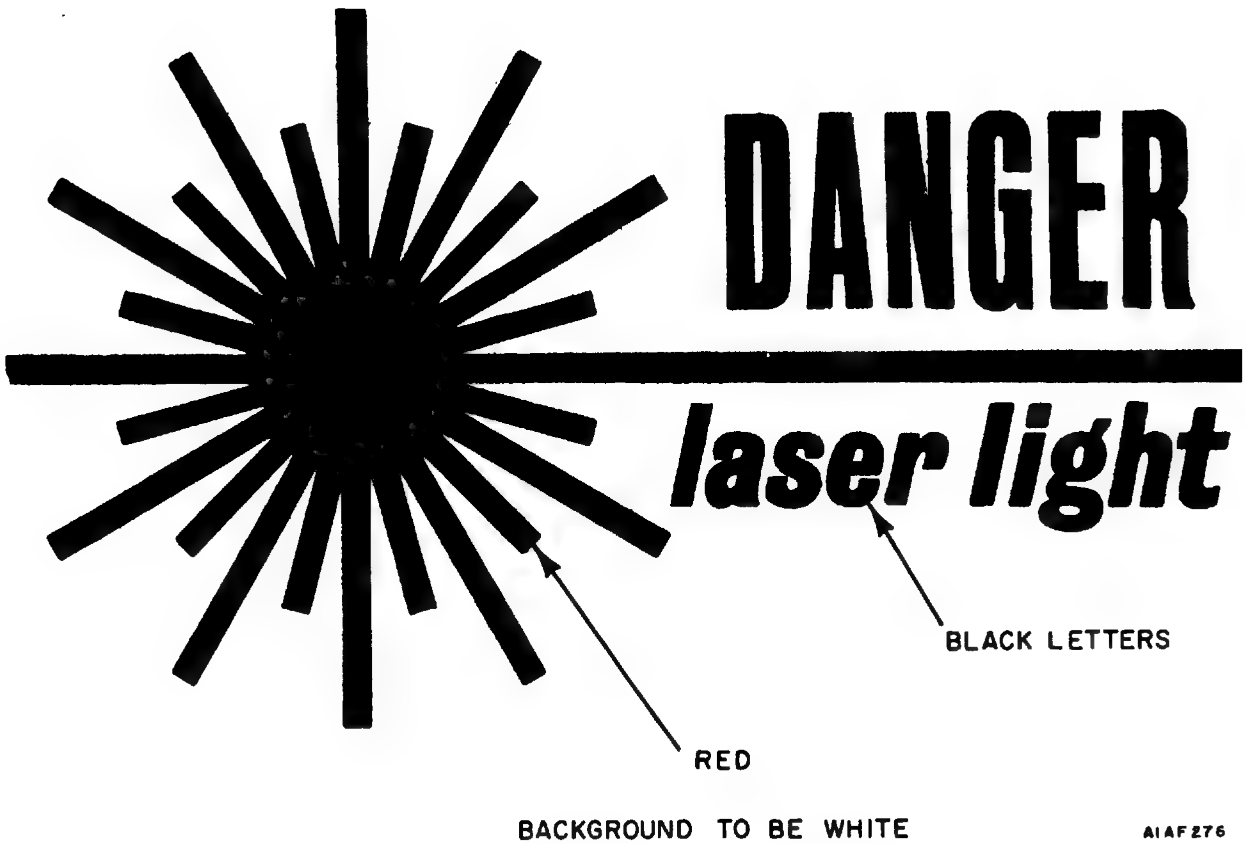


Figure 7-61. Laser Warning Sign

(c) Tracking of non-target vehicular traffic or aircraft should be prohibited if within calculated hazardous distances.

(d) The beam path should be devoid of objects or area capable of producing hazardous reflections.

(e) A permanent log should be maintained, including date, time, place, type of device fired, bearing of beam, and roster of participating personnel.

c. Burns and Shock Hazards Due to EMR. As noted in other sections of this handbook, EMR from antennas of electronic equipment can induce voltages in a variety of metallic objects (such as smokestacks, railings, aircraft, ladders, transmitting and receiving antennas, cranes, booms, etc.) normally found on a naval shore installation, which can result in shocks or burns to personnel. Personnel should be alert at all times to the possibility of burns and shocks from the aforementioned examples and other similar objects not specifically mentioned, as well as the undesirable effects that might result from such an accidental shock, such as violent reactions which can cause a fall from an elevated position or an injury due to striking an object. In addition, the following safety precautions should also be taken:

(1) Only authorized personnel should be permitted in the vicinity of transmitting antennas and on nearby ladders, railings etc.

(2) Personnel working in the vicinity of EMR fields should not wear loose clothing, jewelry or other metallic objects.

(3) Circuits in electronic equipment should be grounded to protect against shocks or burns. If the location of the protecting ground is not in the immediate vicinity of working personnel, suitable warning tags should be employed to prevent unauthorized removal of the protective grounds.

(4) Aircraft should be grounded in accordance with the latest such requirements as should mobile vans containing transmitting antennas.

(5) When cranes, booms or cargo handling equipments are used in the vicinity of transmitting antennas, insulated hooks and other safety devices should be used.

7.7.3 Control of Hazards to Fuels

Possible hazards to flammable mixtures as a result of EMR have been discussed in other portions of this handbook as well as many other publications, such as NAVMAT P-5100, NAVORD OP-3565/NAVAIR 16-1-529, NAVAIR 06-5-502, NAVSHIPS 0900-005-8000, and NAVFAC and NAVAIR documents, instructions and directives. These documents contain minimum safe distances for handling fuels. While these restrictions reflect what is known of the hazard to date, present efforts are being directed towards the elimination of all conditions conducive to arcing during fueling operations. These efforts include the development of fueling nozzles and receptacles providing non-metal-to-metal contact with the aircraft or vehicle being refueled, the use of insulated coatings on areas immediately adjacent to fueling receptacles and vents, and the replacement of metal parts with non-metal parts.

Until, and unless, otherwise required, the precautions in 7.7.1 above and the following precautions should be met during the design, operation and maintenance of fueling and transmitting antenna installations:

a. In areas where gasoline is to be handled, avoidable sources of EMR which may cause ignition should normally be located to a distance determined by safety and good practice; this is usually at least 200 feet for gasoline and at least 50 feet for other flammables. Such sources of EMR include cargo handling vehicles, locomotives, power equipment, electrical equipment not specifically approved for use in hazardous atmospheres, all motor vehicles, and electronic and transmitting equipment and antennas.

b. Fueling sites and operations should not be located in the proximity of antennas. An ungrounded automobile, ungrounded filling nozzle, or merely the attendant's body in close proximity to transmitting antennas may produce sparks sufficient to ignite gasoline vapor when the nozzle comes in contact with the tank opening. Pump nozzles must be grounded at all times, and motor vehicles, when fueling, must also be grounded before opening the tank.

c. No flammable mixtures/materials shall be located or handled in an area where the EMR radiation level exceeds the 10 mW/cm² personnel exposure level. In addition, all transmitters having antennas within a certain minimum distance of shore based handling or fueling areas shall be de-energized as follows:

(1) Transmitters with 250 W radiated output or under shall be de-energized if their antennas are 50 feet or less from handling or fueling areas.

(2) Transmitters with over 250 W radiated output shall be de-energized if their antennas are within 200 feet of handling or fueling areas.

(3) Radar transmitters, having antennas within 200 feet of the handling area regardless of their output power, shall be de-energized if it is possible for the center of the main beam of radiated electromagnetic energy from their antennas to fall directly on any part of the handling or fueling area.

d. In instances where space limitations may occasion the erecting of fueling stations, parking ramps or other structures near an antenna site, the following precautions are to be observed:

(1) All metal used in building wooden structures, within 200 feet of fixed antennas radiating 250 watts or more, shall be bonded together where feasible and grounded to reduce interference and fire hazards.

(2) During gasoline or JP-4 fueling operations within the vicinity of shore based transmitting antennas, especially high power transmitting antennas, particular care should be taken to adequately ground all automobiles, aircraft and other gasoline, JP-4 or LPG powered machines while they are being fueled. In addition, refueling trucks, pumps, filling nozzles, and tanks will also be grounded prior to any delivery of fuel.

e. Radiating antennas (i.e., rotating, scanning, and fixed) shall be positioned, if possible, so as to prevent illumination of fueling areas while in operation. Otherwise, minimum distances, as given above, shall be employed.

f. Additional guidance for potential fuel hazards may be found in NAVELEX 0101,103.

7.7.4 Control of Hazards to Ordnance

This handbook does not attempt to outline in great detail the requirements, restrictions, and procedures for handling ordnance in the presence of EMR. Details on the above, as well as measurements and theoretical analyses, may be found in NAVORD OP-3565/NAVAIR 16-1-529, NAVWEPS OD 30393, MIL-P-24014 and other documents. For the purpose of this handbook, it is sufficient to say that weapons systems and associated subsystems, equipments and devices may be tactically deployed on shore stations and therefore may be transported, stored, handled, loaded in launchers, launched, serviced, disassembled, checked and tested in the vicinity of EMR generating equipments. Accordingly, in the planning and design of shore installations and operation and maintenance of ordnance devices, the following precautions, in addition to those in the aforementioned documents and paragraph 7.7.1 of this handbook, are to be met:

a. Weapons and weapon-launcher systems should be grounded according to MIL-B-5087 or the applicable weapon system specification.

b. Access doors should not be opened if the system, or associated subsystems, are located in an EMR field.

c. The handling of weapons, EED's, etc., should not be carried out in the presence of known EMR fields; safe distances as determined by NAVAIR and NAVORD should be used in a manner similar to that for fueling operations.

d. When working in the vicinity of weapons, systems personnel should not touch conductors that lead into the actual weapon.

e. In an EMR field, the launcher and weapons are very likely to be at different voltage potentials which, therefore, increases the possibility of generating an arc when mating the umbilical. After the weapon has been secured to the launcher, the potentials are almost the same and the possibility of an arc is reduced. The latest weapon system design criteria promulgated by NAVORD will reduce the possibility of EMR hazards to ordnance.

f. If an ordnance site is located near a transmitter antenna installation and a weapon is transported in a susceptible condition, partially assembled or with exposed wiring, the shipping crate should be made of sheet metal and should completely enclose the weapon.

g. Since EMR energy of any type may cause inadvertent ignition of ordnance components, motor vehicles equipped with radio transmitters shall not transport electric blasting caps or other electrically fired ordnance. Radio transmitters in any motor vehicle are not to be operated within 25 feet of any area where electric blasting caps are to be located and transmitters with an output of 250 watts or more shall not be operated within 100 feet of such areas.

h. Activity regulations concerning electrical blasting shall take into account the location and characteristics of electronic transmitters both within and outside the confines of the activity. Regulations to minimize this hazard shall comply with precautions described in The American National Standards Institute Guide C95.4 of March 1971, "Safety Guide for the Prevention of Radio Frequency Radiation Hazards in the Use of Electric Blasting Caps."

i. All future planning for shore based communications transmitters, radars, or other such installations transmitting high energy electromagnetic fields are to be based on locating such transmitting installations not closer than 1000 feet from any ammunition magazine, ammunition operating building, road used for transporting ammunition, or any area where ammunition or explosives are regularly handled.

7.7.5 Control of Hazards of Electronic Devices

Protection measures to safeguard electronic devices from damage due to EMR should be considered from the initial design stages of the equipments and carried through the installation design and operation phases. Grounding, bonding, shielding, circuit design, chassis layout and other techniques are now being employed to minimize equipment degradation due to EMR. These are treated in the EMC portion of this handbook and may be applied to prevent equipment damage. However, equipment damage is not, as yet considered in the design. Accordingly, the selection of equipment locations to prevent illumination from radiating antennas becomes increasingly important, as does the installation criteria.

Particular attention should be paid to the location of medical electronic devices in relation to transmitting antennas as EMR from the antennas can cause damage to the sensitive medical devices. Relative location of medical monitoring devices (i.e., electrocardiographs, cardiac monitors etc) must also be considered.

When using some of the medical electronic devices described above, such as the EEG, the ground integrity should be checked just before a patient is connected to any line operated device. The use of molded line plugs should be abandoned because they cannot be inspected for broken ground connections.

Hospitals on naval installations must also plan for and establish maintenance programs, such as performing routine checks and measurements of leakage currents so that early symptoms of equipment failure can be identified.

When shipping electronic components for subsequent use in electronic equipments and systems care must be exercised to avoid transporting them in EMR fields. If this cannot be avoided, the components should be packed in a suitable shielded container.

7.7.6 Special Safety Precautions During EMR Measurements

The measurement of a potentially hazardous field implies that some danger will exist for measurement personnel. The first step that should be taken to minimize such danger is to operate the radiating systems at a known reduced power. The field pattern may then be defined and the reduced power density values recorded. Proportional relationships are then used to calculate the maximum power density at the same point in the pattern when the radiator is operated at its maximum power.

A second precaution should also be exercised in all radiation measurements. The site plan and predicted radiation pattern should be studied by the measurement personnel so that a suitable starting point well away from the radiator(s) is chosen. This starting point should have less than the maximum predicted power density and subsequent measures should be made by moving toward the radiating source(s). Personnel should be cautioned that the maximum power density will exist at some calculated distance from the radiator in order that they will be constantly alert for abrupt energy level changes in the near field.

Most radiation measuring devices use a directional antenna which must be pointed toward the source to be measured. Users of such devices must be instructed to scan potential reflectors as well as the primary radiators when measuring the reflected energy, especially when operating at reduced power. The tendency may be to neglect such secondary sources due to an apparently low power density, forgetting that when the same reading is used to establish the maximum power level, a hazardous condition might be indicated.

The measured power density levels should be recorded on a site plan for comparison with those levels resulting from the prediction process. Considerable care should be exercised to picture the site in three dimensions when comparing levels and assigning hazardous labels to particular areas. Highly directive antennas may have their major beams crossing a particular area such that a hazard appears to exist but upon considering a difference in vertical angles the hazard may completely disappear.

Any extreme difference between measured and predicted levels should not be disregarded since inaccuracies in the prediction process are present. In any such case where doubt arises, the measured value should be given precedence in decision making. The combination of the measured and predicted results should remain as real factors in the final determination of existing hazards.

Upon completion of a radiation hazard survey and analysis, certain discrete areas may be defined on the site plans as being hazardous, either to personnel, fueling operations, or to electronic or ordnance devices. Steps must then be initiated to convey the warning of the danger to using personnel as well as to itinerants. Such warning is commonly provided by the standard warning signs described earlier. Fences and other obstacles or more active measures are taken to alleviate the hazardous condition by installing interlocks, cut-outs, or delay mechanisms. Care must be exercised in the employment of these methods since some of them may have direct bearing on the functional utility of the systems involved.

APPENDIX A

EMC/RADHAZ PROGRAM PLAN OUTLINE

This appendix presents an outline for the EMC/RADHAZ Program Plan discussed in the basic portion of this handbook. Applicable portions of the outline are to be used as a basis for the content of the plan which is to be integrated with and become part of the BESEP.

A.1 INTRODUCTION

A.1.1 Purpose of Plan

The purpose of the plan shall be stated. This should in effect be a summary of the program required to achieve an EMC and RADHAZ free installation or system.

A.1.2 Purpose of Installation/System

The overall installation or system shall be summarized.

A.1.3 Requirements

Specific operational and installation requirements shall be stated. Particular requirements and actions of the NAVELEX Field Activity or Division shall be included.

A.2 APPLICABLE DOCUMENTS

A.2.1 Military Standards and Specifications

List of military standards and specifications which are to be imposed on the installation or system, and associated subsystems. For example, MIL-STD-461/462/469/449.

A.2.2 Other Manuals, Handbooks and Documents

List of manuals, handbooks and other documents containing requirements which are to be invoked shall be included. For example, other documents of the Naval Shore Electronics Criteria Handbook series, ANSI standards on RADHAZ (i.e., Warning Sign), other SYSCOM and Navy publications containing siting or installation criteria and EMI suppression techniques, etc.

A.3 DESCRIPTION OF INSTALLATION/SYSTEM

A.3.1 Intended Function

A brief description of the intended function of the installation or system shall be given. In addition the following should be addressed.

a. Is intelligence to be transmitted? If so, what type? How will it be used? For what purpose?

b. What is the allowable maintenance or down-time?

c. Will the system operate continuously?

d. If a back-up is required, will it operate exactly as the primary?

e. Do any equipments or subsystems perform critical operations which can effect mission success or safety?

f. What is the transmission medium?

g. Is signal processing equipment to be used?

h. Will all the equipments and subsystems be manned during operation?

A.3.2 Specific Operational or Environmental Characteristics

The following items should be addressed if known:

a. What is the electromagnetic environment in which the installation will be sited?

b. What environmental factors are there that may adversely affect radiation?

c. Will environmental conditions require special parts and materials in order to maintain reliable operation?

d. What effects do environmental conditions have on the installation of the equipment required to generate, radiate or receive the electromagnetic energy?

e. How will environmental conditions effect the signal-to-noise ratio?

f. Are the operating frequencies vulnerable to atmospheric, natural, or man-made noise at the intended installation?

g. Will the antenna patterns be affected by objects in the vicinity or local terrain?

h. Will there be any other devices in the area that could cause interference to your equipment? If so, what are the functions and characteristics of these other devices? Are there any coupling mechanisms? Have emission or susceptibility measurements been made on these other devices?

i. What effect would interference have on transmissions?

j. What would be the effect of poor ground conductivity?

k. Is real estate available at ground station locations?

l. Is there sufficient space available to house necessary equipment or subsystem for all of the possible operating frequencies?

A.3.3 Type and Characteristics of Equipments/Subsystems to be Installed on Site

A brief description of the devices to be used in the installation should be included, with specific attention to electronic warfare, cryptographic, nuclear detection and ordnance equipment, and the required sensitivities of receiving equipments and operating frequencies of all equipments.

A.4 DESIGN CRITERIA

The overall EMC and RADHAZ control approaches to be taken and the basis for them should be discussed. Shielding, bonding, grounding, cable routing, location of potential hazard, warning signs/alarms, special hazard reduction equipment or techniques (i.e., fuel nozzles, antenna location, use of protective clothing, etc.) should be covered.

Mechanical design considerations shall be described including construction techniques and materials to be used to provide inherent attenuation to EMR.

A.5 ANALYSIS

Prediction and analysis techniques employed to determine potential RADHAZ and EMI problems should be described and predictions performed to date included. Potential problems should be identified as well as the steps to be taken to eliminate each problem.

A.6 TEST AND EVALUATION

The test program deemed necessary to demonstrate EMC and identify possible RADHAZ after installation of all equipments subsystems and systems shall be described. Detailed tests are to be included in the test plan.

A.7 FREQUENCY MANAGEMENT

Statements should be included addressing frequency management aspects of the program including frequency assignment and allocations. Consideration must be given to obtaining frequency allocations for the equipments and subsystems operation, as well as for testing purposes.

A.8 MANAGEMENT

A.8.1 Organization

A description of the organizational responsibilities,lines of authority and control in the activity's organization to show how the EMC/RADHAZ program is to be managed within the overall program framework.

This shall include a definition of responsibility for the program for items and for services which are contracted.

A.8.2 Program Control

A description of installation design reviews and other means of control shall be given.

A.8.3 Schedules

A schedule shall be given describing the milestones for the EMC/RADHAZ program and it shall show how these milestones fit with key overall project.

APPENDIX B

EMC/RADHAZ MEASUREMENT PROGRAM

B.1 SCOPE OF APPENDIX

Various aspects of EMC and RADHAZ have been presented in the basic portion of this handbook. One exception concerns the measurement program required to actually demonstrate EMC or to identify the presence of RADHAZ. Due to the constantly changing technology associated with such measurements, discussion of the overall measurement program has been included as a separate appendix. This will facilitate the updating of the measurement portion of the handbook as the technology advances. The following paragraphs outline general and specific considerations associated with measurements for EMC and RADHAZ. All portions of this appendix will not be applicable for all measurement programs. Therefore, prior to embarking on a measurement program this appendix should be reviewed and applicable portions selected for implementation.

It is also noted that NAVELEXINST 5100.4 indicates that NAVELECSYSCOM field divisions and activities may be required to provide field strength measurements of the electromagnetic environment for RADHAZ evaluations. Applicable portions of this Appendix should also be used for these measurements.

In approaching the measurement program for EMC it is assumed that individual equipments and subsystems which are to be located on the shore station in question have complied with the applicable emission and susceptibility criteria in MIL-STD-461/462 as well as the requirements in MIL-STD-469 for radars. If such is not the case, these equipments should be examined initially when the installation measurements reveal electromagnetic incompatibility.

B.2 GENERAL CONSIDERATIONS FOR INSTALLATION TESTING

Standards for evaluating installations or systems for EMC and RADHAZ are not, generally, available. Therefore, accurate evaluations require a great deal of judgement in predicting or anticipating the operational electromagnetic environment. Thorough evaluations must also consider the required performance characteristics and missions of the installation or system, and associated subsystems. Information gathered from the MIL-STD-461/462 type evaluations of individual equipments to be installed will be useful in evaluating overall system or installation operation and performance.

In order to clarify the system or installation evaluations to be discussed herein, it is necessary to distinguish between "intra" and "inter"-system or installation EMC/RADHAZ evaluations. The former refers to determinations of potential RADHAZ or degradation of the intended performance or mission of equipments or subsystems in a given installation or system as a result of emissions generated by devices internal to, or within that installation or system. Use is made of data obtained from MIL-STD-461/462 measurements of conducted and radiated emission and susceptibility characteristics of the various equipments. Knowledge of the general layout of the final installation or system will enable predictions, as described in Chapter 6 of this handbook, to be performed for intra- and inter-system or installation of EMC and RADHAZ. Evaluations for inter-system or installation of EMC and RADHAZ must be made in the intended operational environment. Emissions must be anticipated from all (i.e., Navy, DOD, other government agencies, and commercial) electronic and electrical emitters in the vicinity, as well as nearby power lines. With this information and the susceptibility characteristics of devices installed in the system or installation, it is possible to determine the presence of RADHAZ as well as performance or emission degradation. The extent, level, and identity of emissions associated with shore electronic

installations will vary greatly. If, at a specific planned site all emitters on, or in the vicinity of, the installations are known, or can be predicted from information obtainable from ECAC (see Chapter 1), along with the electrical characteristics, actual surveys or measurements may not be needed. Knowing the above information, field intensities and power densities can be predicted. If, however, measurements are necessary, they should be approached in an orderly manner, starting with preparation of a test plan to describe the testing procedures that will be used to demonstrate EMC or determine the existence of RADHAZ. In general, the test plans indicate measurement objectives, test configurations, test frequencies and points, detailed measuring procedures and the format for recording data. Test procedures should be described in sufficient detail to enable duplication of the proposed methods since data obtained from the measurements may necessitate corrective actions to eliminate or minimize hazards or interference. Finally, upon completion of the testing programs, test reports are to be prepared in sufficient detail to permit the required analyses for EMC or RADHAZ.

Additional details on various aspects of EMC and RADHAZ measurements are discussed below. It is noted that details for RADHAZ measurement evaluations are also applicable for EMC evaluations.

B.3 EMC MEASUREMENTS

B.3.1 Testing Concepts

The complete EMC survey may cover the frequency range of 30 Hz to above 40 GHz, depending on the equipment used in the installation and will consider both inter- and intra-installation or system of EMC, with the major objective to demonstrate total installation EMC under operational conditions. Tests should be designed to investigate and locate every potential source and victim of EMI via the mechanism inherent in the actual operational environment. Because the tests include basic equipments and subsystems in the installation, as well as all of the electrical and other electronic equipments in the system or installation, the EMC survey is quite lengthy in both preparation and implementation.

Test procedures and instrumentation required to perform realistic EMC tests are to be detailed in the test plan. There are several basic approaches that may be followed, either singly or collectively to demonstrate EMC.

a. Emissions may be injected into the system or installation at critical points. Injected conducted emissions must be at a level somewhat higher (for example 6dB) than pre-determined ambient environment levels. Appropriate test points must then be monitored for malfunction indications.

b. A second approach that may be used to test for a safety margin (i.e., 6 dB) between equipment susceptibility and emission levels generated within the system or installation, is to increase the system or installation sensitivity level so that its susceptibility level to interference is increased by the required safety margin. With this approach, it is also necessary to monitor test points for malfunctions. The increase in sensitivity is often difficult to achieve and therefore this approach is seldom used.

c. A third approach that may be used is to measure susceptibilities of key subsystems or equipments and compare these measured levels with existing or predicted emission levels to determine if the required safety or interference margin exists.

Each of the above approaches has certain advantages and disadvantages. The best approach will depend on the particular installation or system under consideration and should be documented in the test plan.

B.3.2 Degradation/Malfunction Criteria

In order to evaluate the effectiveness of a system or installation it is necessary to evaluate how the various associated subsystems and equipments are affected by emissions. This necessitates defining what constitutes a malfunction or degradation of performance and measurement techniques.

To do this, it must be indicated how the degradation will affect the operational performance. In some cases, the environmental conditions must be designated under which the presence of potentially interfering (undesired) emissions or other forms of electromagnetic energy will be barely detectable in the output of the various equipments and subsystems. In many instances, the system of design is such that substantially more than barely detectable signals must be impressed before degradation of performance occurs. This is because the associated subsystems and equipments if designed to MIL-STD-461 have a certain amount of immunity. Some judgement will, therefore, have to be exercised in specifying the emission levels at which actual degradation of performance will occur. Presumably, a technician with adequate experience can make a fair estimate of such things as when data transmission circuits will begin to produce errors, when target indicators will begin to become confused by extraneous indications, and when communications circuits are sufficiently degraded that information transmission is difficult to maintain or is otherwise unsatisfactory. Accordingly, the 6 dB figure cited above should not be construed as the sole criteria to use.

Eventually, it is expected that performance and malfunction criteria pertaining to overall operation will become more explicit and quantitative than at the present time.

B.3.3 Installation/System Operation

To meaningfully test for EMC, it is necessary to operate all equipments and subsystems in the installation or system as expected during the execution of all of its intended missions. It should be operated under load as in "real-life" - at least to the extent economically permissible. Time-dependent operations of the various equipments one at a time and recording EMI malfunctions, if any, may have little resemblance to real-life situations since an installation generally has a number of devices actuated at any one time. On the other hand, turning on all devices simultaneously will probably create a situation which also will never occur in real life. Accordingly, the off-on modes of operation of the devices and equipments of an installation or system should be documented in the test plan and followed. Aside from the basically required interference measuring equipment (which sometimes can be minimized if adequate secondary instrumentation usage is approved), test equipment such as signal generators, oscilloscopes, spectrum analyzers, frequency meters or counters, cameras, audio amplifiers, and/or special receivers may be required. Included in the signal generator class are those special signal sources needed to provide simulation of the subsystems or equipments be they random pulse, function, sine, square, video, transient, or audio devices. The use of amateur radio or military surplus transmitters can sometimes even be used as EM energy sources instead of more costly high power signal generators (provided that radiated spectrum is relatively clean). The audio amplifiers need not be special.

Of particular concern is the choice of measuring antennas for radiated emission tests. The following antennas are commonly used and are acceptable for the EMC testing described herein (See Table B - 1).

Antenna factors are to be included in the test plan or test report. Procedures for antenna calibration are included in MIL-STD-461/462 and the SAE ARP 958.

B.3.4 Monitoring the Installation or System

Malfunctions may be sensed and recorded using personnel to man the stations of output display devices, such as panel meters, recorders, scope displays, digital presentations, etc., in which the outputs are intended for human consumption. Malfunctions may also be monitored automatically by sensors which record a voltage or current which is an analog of the sensed parameter. This technique is especially important where events are occurring too rapidly for humans to follow or where more automation of malfunction versus mission time sequence is desired for economic reasons. Concurrently with the latter approach, certain auxiliary instruments may be used to help locate victims and sources of EMI. For example, current probes on one or more busses or wiring harnesses may be used, as may electric field antennas for probing certain areas. For these data recordings, plots of amplitude (usually peak readings) versus time are made to permit all data to be presented on an event-reaction versus time basis. This allows cause and effect analyses to be made.

B.3.5 Instrumentation Considerations

As previously stated, EMC testing involves instrumentation to record emission levels of voltage or current on critical circuits and the effects of the emissions in outputs of critical devices. In most instances, these tests are performed over a period of time during which continuous recordings may be required. As a result, a wide range of test equipments may be required. EMC instrumentation requirements are covered in many of the referenced documents as well as several military standards, such as MIL-STD-461/462/449 and 469, and therefore will not be detailed herein. General factors to consider when selecting instrumentation, however, are presented in the following paragraphs. Oscilloscopes and spectrum analyzers are fast becoming favorite test tools. A camera may be added to these units to provide a permanent record. For transient amplitude measurements and analysis this is one of the only ways to record the events as they occur. The use of current probes with these instruments further increases their utility. Logarithmic sweep adapters are available for many oscilloscopes making possible the display of information normally presented on graph paper.

The instrumentation to be used should be described in the test plan.

B.3.6 Test-Site Ambient Electromagnetic Environment

The ambient electromagnetic during testing must be monitored, measured, analyzed, and perhaps controlled, to ensure that it does not degrade test results or mask EMI. When possible, all support or site equipment that generates EMI should be suppressed, removed or not operated. Ambient signals that degrade test results should be identified. For signals that may be present only randomly, such as from commercial or mobile communications stations, it may be possible to perform EMC testing while the signals are not broadcasting.

Some emissions may be arriving at the test site by ionospheric propagation. Such signals will usually be below 30 MHz. These emissions may be present for 24 hours. However, due to the daily changes in ionospheric propagation, tests in this frequency range may be scheduled for times when the offending emissions are relatively quiet. CCIR 322 can be used to estimate these levels.

Certain frequencies in the broadcast FM and TV bands may cause problems. The approach in this case is to postpone measurements in these frequency ranges until the offending stations sign off. This approach may also be used where certain noncommercial ambient emissions are on only during the normal work day. For example, the checkout of an engine-generator set can be arranged outside normal working hours so that such industrial equipment as welders, milling machines, lathes, reproduction machines, etc., can be turned off without disturbing normal operation.

The characteristics of certain ambient emissions allow the human ear to discriminate between them and the emission from the test sample. This approach may be used where the ambient emissions are clicks caused by a switching device and the emission of interest is a pulse with a steady repetition rate. The level of the ambient emission should not be too far above the emission of interest, lest the emission of interest be inaudible.

EMC measurements at times must be made in areas where other electronic tests are being performed. Managers of these areas can do much toward ensuring that the ambient is kept within reason, providing it is handled in a timely manner. Some offending items that should be kept out of the test area during EMC tests provided with appropriate means of suppression are:

a. Vehicles with ignition systems. These may be replaced with diesel units or suppressed.
b. Motor-generator sets. These units may be of brushless design, or located in shielded enclosures with filtered input and output lines.
c. Facility appliances (switching units, such as heater or elevator switches, and many motor units such as refrigeration units, fans, etc.).

When considering ambients, the conducted ambient level should not be overlooked. Ambient emissions can be conducted to the test area and critical devices via power lines. They can be conducted a considerable distance. Therefore, when evaluating the ambient electromagnetic levels, the following should be considered: power lines; telephone lines; commercial radio relay lines; nearby industrial activity; and equipments operated on the installation.

B.4 EMR HAZARDS MEASUREMENTS

Measurement procedures to determine hazardous levels of EMR at shore installations have been developed and used for some time. Various aspects of these procedures are included herein to facilitate and standardize to some extent EMR measurements at shore sites.

B.4.1 Near and Far Field Measurement Considerations

The electric field radiated by a particular transmitting antenna can be measured in either the near field or far field as discussed in other chapters of this handbook. There is no sharp dividing line between the two regions and the somewhat arbitrary limits set for each region are based on the way in which the energy spreads as the distance from the antenna increases since the energy is not spread uniformly across the antenna in the near field region and does not have a fixed density value with distance from the antenna as it does in the far field region. This being the case, the far field region is normally selected to perform measurements. The far field regions appear at a substantial distance from the transmitting antenna. At this point the power density begins to decrease in proportion to the inverse square of the distance from the antenna. The far field region begins at a distance $d = 2(D_t + D_m)^2/\lambda$ where D_t = diameter of the transmitting antenna, D_m = diameter of measuring antenna, and λ= wavelength.

B.4.2 Equipment Selection

Factors are now covered for measuring and identifying the extent of electromagnetic radiation in a field created by an unknown source or sources of radiation at a specific site on or around an installation. Power meters, field intensity meters, and spectrum analyzers can be used as measuring instruments. The power meter is a broadband device from which levels of power density can be determined, but in order to identify the frequency of the sources of the electromagnetic radiation, a frequency selective device such as the Field Intensity Meter (FIM) or spectrum analyzer must be used. Regardless of which test instrument is used to measure an unknown field, the proper receiving antenna or antennas must be selected and properly oriented. For example, the possible radiation may originate from a directional type antenna or antennas. In this case the receiving antenna must be rotated 360° in azimuth in order to maximize on the radiated emission or emissions. The spectrum analyzer has the capability as a frequency selective device or broadband measuring device with varying spectrum widths. Many FIM have automated sweep frequency capability along with an X-Y recorder output. For devices without the automatic sweep capability, manual sweeping can obtain acceptable results. When using an FIM, which is a frequency selective device to scan the frequency field in question, several frequency scans may be required along with different orientation of the proper receiving antenna or antennas, in order to investigate the frequency operation properly. Once the presence of an emission or emissions and the approximate level or levels determined, then the selected emissions can be measured and power density levels determined and identified by frequency if required.

B.4.3 Measurements in High Level Fields

In performing measurements close in or in the near field, there exists the possibility of obtaining erroneous reading on the monitoring device due to the presence of a high level radiation field which exceeds the shielding capability of the measuring device. To determine if case penetration is present, terminate the signal input of the monitoring device, and with minimum attenuation settings, observe the meter indication, if any. In the event there is a meter indication then case penetration is considered. To counteract this situation a shielded enclosure must be used which provides sufficient shielding in order to obtain valid data, or move the instrument away from the beam of the radiator.

B.4.4 Multiple Sources

The superimposed fields of multiple frequencies (several transmitters) may be strong enough to cause a radiation hazard even though each individual transmitter cannot. In this situation a frequency selective measuring instrument is necessary such as a spectrum analyzer or RIFI meter. Each transmitter is treated as a single source. After the results are obtained for each individual transmitter then:

a. Determine the ratio (EM/EC) for each transmitter. EC is equal to the hazard requirement for the particular situation and EM is equal to either the calculated or the measured power of the individual transmitter.

b. Square the ratios (one for each transmitter) and add them:

$\left(\frac{EM_1}{EC_1}\right)^2 + \left(\frac{EM_2}{EC_2}\right)^2 + \ldots\ldots$ (10). If they are equal to or greater than 1, a hazard exists.

If the ratio is less than 1, no hazard exists.

B.4.5 Calculations

B.4.5.1 Converting Field Intensities to Power Densities

Some relationships that are quite useful in converting field intensity measurements are presented below:

$$P = \frac{E^2}{120\pi} \qquad \text{(B-1)}$$

P = Power density in watt/meter^2

E = Electric field intensity in volts/meter

120π = Resistance of free space

For convenience this can be expressed in logarithmic form for watts, milliwatts, volts, and microvolts.

dBW/m^2	=	dBV/m	–	25.8	(B-2)
dBW/m^2	=	dBμV/m	–	145.8	(B-3)
dBm/m^2	=	dBμV/m	–	115.8	(B-4)
dBm/cm^2	=	dBμV/m	–	155.8	(B-5)
dBm/cm^2	=	dBV/m	–	35.8	(B-6)
dBW/m^2	=	dBm/m^2	–	30	(B-7)
dBW/m^2	=	dBW/cm^2	+	40	(B-8)
dBW/m^2	=	dBm/cm^2	+	10	(B-9)

B.4.5.2 Received Power

Calculations of received power can be made as follows:

$$P_r = \frac{A_r A_t P_t}{(\lambda R)^2} \qquad \text{(B-10)}$$

where:

P_r = received power in watts
A_r = receiving antenna effective area in meters
A_t = transmitting antenna effective area in meters
P_t = transmitter average radiated power in watts
λ = wavelength of transmitted signal in meters
R = distance between transmitting and receiving antennas in meters.

In addition,

$$P_r = \frac{G_r G_t P_t \lambda^2}{(4\pi R^2)} \tag{B-11}$$

$$P_r = \left(\frac{G_r G_t P_t}{f\,[\,\mathrm{MHz}\,]\,R^2}\right)\left(\frac{984}{4\pi}\right)^2 \tag{B-12}$$

where:

f = transmitter frequency in MHz and R = distance in feet
If P_t is in watts, then P_r is also in watts.
Written in logarithmic form equation (B-12) becomes:

$$P_r = 37 + G_r + G_t + P_t - 20 \text{ Log } R - 20 \text{ Log } f \tag{B-13}$$

where:

P_r = received power in dBm if P_t is also in dBm.

Equation (B-13) enables simple addition and subtraction of the factors needed to predict received power.

An alternate method of prediction for power density of an emission at a given distance from the transmitting antenna utilizes the following equation:

$$P_d = \frac{P_t G_t}{4\pi R^2} \tag{B-14}$$

where:

P_d = power density in watts/m^2 (milliwatts/m^2)
P_t = transmitter average power output in watts (milliwatts)
R = distance between site of interest and transmitter antenna in meters
G_t = transmitter antenna gain

$$P_d = P_t + G_t - 11 - 20 \text{ Log } R, \tag{B-15}$$

where:

P_d is in dBW (dBm)/m^2, P_t is in dBW (dBm) and G_t is in dB, which reduced the math to simple addition and subtraction.

To obtain power density from the received power, we can use the following relations:

$$P_d = \frac{P_r}{A_r} \quad \text{Where } A_r = \text{effective area } (m^2) \tag{B-16}$$

$$A_r = \frac{G_r \lambda^2}{4\pi} \tag{B-17}$$

Hence, $$P_d = \frac{4\pi P_r}{G_r \lambda^2} \tag{B-18}$$

or expressed logarithmically:

$$P_d\ (\text{dBm/m}^2) = 11 + P_r\ (\text{dBm}) - G_r\ (\text{dB}) - 20 \text{ Log } \lambda \tag{B-19}$$

Correcting for cable loss (A_o) from the antenna, we now have:

$$P_d\ (\text{dBm/m}^2) = 11 + P_r\ (\text{dBm}) + A_o\ (\text{dB}) - G_r\ (\text{dB}) - 20 \text{ Log } \lambda \tag{B-20}$$

B.4.5.3 Comparisons With Predicted EMR Levels

In order to compare the measured EMR levels with predicted levels, refer to the Power Density nomogram in figure B-1 of this Appendix and use the following procedure:

a. Locate the transmitter output on the P_t scale.
b. Locate the gain of the transmitting antenna on the G_t scale.
c. Connect a straightedge between these two points and note the reading on the P_t G_t scale.
d. From this point on the P_t G_t scale connect a straightedge to the distance which is the antenna separation located on the R scale.
e. Note the reading on the P_d scale. This level is the predicted power density at the point of interest.

To determine the power that one's instruments should measure at this point, refer to the Effective Area and Received Power nomogram in figure B-2 of this Appendix.

a. Locate the gain of the receiving antenna on the G_r scale.
b. Locate the transmitting frequency on the frequency scale.
c. Connect a straightedge between the two points and note the reading on the A_e scale,
d. Connect a straightedge from the reading on the A_e scale to a point on the P_d scale which represents the approximated power density obtained from the Power Density Nomogram.
e. Note the reading in dBm on the P_r scale.
f. Correct for cable loss by adding the attenuation of the receiving cable to the value obtained in (e.) and determine what the measuring instrument should read. This predicted value should be very close to the actual measured value. If the result is desired in dB volts/meter instead of dBm/m² scale, refer to paragraph B.4.5.2.

B.4.6 Testing for RADHAZ to Fuels

B.4.6.1 Necessity for Testing

Many factors affect the creation of an environment favorable to the ignition of fuel vapor by RF-induced arcs. Some of these have been discussed in other portions of this handbook, but are also listed.

a. Fuel
   (1) Fuel/air mixture ratio
   (2) Type of fuel (aviation gasoline, jet fuel, etc.)

b. Electromagnetic Environment
   (1) Transmitter power
   (2) Frequency
   (3) Type and characteristics of antenna (gain, polarization, etc.)
   (4) Ground conductivity

c. Installation or System Geometry
   (1) Aircraft or vehicle orientation with reference to antenna
   (2) Distance from antenna
   (3) Type of aircraft (wing span, location of filler vents on wing, etc.) or vehicle
   (4) Presence of nearby reflecting bodies
   (5) Length and orientation of nozzle and filler hose with reference to both aircraft or vehicle and transmitting antennas
   (6) Ambient winds.

B.4.6.2 Measurements

The purpose of the measurements are to determine several of the more important fuel-hazard parameters at a Naval Shore Station where such a hazard is known to exist and, on the basis of these measurements, to establish general distance separation and transmitter power criteria for the planning at other Naval Shore Stations. The effectiveness of several proposed corrective measures will be determined.

The major part of the measurements required are outlined below. Details on the particular type of instrumentation employed (type, serial number, manufacturer), lead lengths, provisions for shielding and grounding, and the physical environment (wind, temperature, humidity, etc.) should be recorded.

a. Field Intensity Measurements. For a specified transmitter power output and for several frequencies across the HF band (i.e., 2, 8, 30 MHz), the field intensity will be measured at various selected points within the normal refueling area and adjacent to the antenna complex. Both vertical–and horizontal-polarized components of the electric field will be measured at specified heights above the ground. The pickup antenna will be oriented in the horizontal plane to obtain a maximum reading. Its direction will also be noted. Distances from these points to the transmitting antenna should be recorded.

Because of mismatch problems between the antenna, transmission line, and transmitter, the degree of mismatch, evidenced by VSWR on the line, should also be recorded at both ends of the transmission line. The type and length of both the transmission line and the antenna are to be noted. The transmitter need not be modulated for these tests, since correction factors can be applied later to determine peak instantaneous powers at the modulation crests; i.e., for 100% AM modulation, the peak instantaneous power is eight times the average unmodulated power. Average ground conductivity should also be noted.

To minimize the influence of reflecting bodies such as nearby aircraft, personnel, trucks, etc., these measurements should be made in a roped-off area. Proximity effects due to personnel taking the readings may cause erroneous data, so remote readings via a telescope may be necessary. Providing adequate shielding of the instrumentation, signal, and power leads will likely be a problem before repeatable data can be taken. Calibration of the field intensity meters both prior to and immediately after these tests is desirable to insure accurate data.

b. RF Voltage and Current. When evaluating RADHAZ to fuels for air stations, measurements on several typical Naval aircraft (fighters, patrol, training, etc.) should be made of the RF-induced voltages and current between selected points along the aircraft wing (both sides) and the nozzle of a purged fuel truck. These aircraft should be located at the same points in the refueling area as in (a.) above, and for the aircraft axis, both

transverse and longitudinal, to the direction of the transmitting antenna. These measurements will be performed for the specified frequencies as in (a.) above. A simple jig made from plastic or wood to maintain the refueling nozzle, and line in a realistic but fixed orientation, will be required. Variable spacing of the nozzle lip from the aircraft skin will be provided, with these data being recorded. Some consideration should be given for providing a simple mechanism that will simulate the nozzle being lifted from the skin. The configuration of the nozzle lip (its radius of curvature and diameter) should be recorded. Because of high RF-induced currents on all metallic structures and test gear in the near field of the antenna, efforts will be required to provide adequate shielding of the RF voltmeter, its leads, input power lines, etc. Battery-powered instrumentation would eliminate coupled interference through the power cords. It is essential that the voltage and current at the point where the arc is formed be measured. To provide measurement of RF current a low-resistance (1 ohm or less) resistor across the electrodes may be necessary.

c. Hazardous Atmosphere. For various types of fuels (aviation gasoline, JP-4, JP-5, etc.) the fuel-air mixtures should be sampled at and near the refueling vents on several typical aircraft and the ratios measured. Fuel should be spilled intentionally on the wing and the resulting gaseous mixture ratios measured. Instrumentation required will be a vapor-detector unit. Attention in the measurements will be given to the time-lag (if any) in the detector response and its capability to spatially resolve the volume of fuel-air mixture (whether the sampled volume is 1 cm^3 or 1 m^3). A time history of the fuel-air mixture at several specified points is desired, if such can be made. Winds, temperature, humidity, etc., are factors which will affect the dispersal of hazardous mixtures so that such data should be recorded.

d. Effectiveness of Proposed Corrective Measures. The effectiveness of several proposed corrective techniques should be determined. Short grounding straps or braid between a point on the refueling nozzle and the aircraft may provide a low reactance path to ground and prevent any arc buildup at the nozzle when it is pulled away from the aircraft. Another suggested technique is the use of an insulated sleeve. These techniques will be evaluated by measuring the RF voltages and currents as in (b.). Tests will be made for the worst case found in (b.). Tests at night make arc detection easier.

e. Problems in HF Measurements. For E-Field measurements, at least a 9-foot square (per side) ground plane should be used to reduce variations to plus or minus 0.5 dB. With smaller ground planes (such as those normally supplied with an equipment by the manufacturer) variations up to plus or minus 10 dB were found. For convenience it is recommended that a loop antenna be used for measurements in the HF range and below.

Because there are such a multitude of factors, attempts to treat this problem analytically are not feasible. A carefully controlled measurement program must be used which hopefully will provide some basis for deciding if potentially hazardous situations exist at Naval Shore Stations. In addition, it is essential that a sufficient number of tests be performed for each condition to provide some degree of statistical repeatability. "Sufficient tests" represents a compromise between time and cost limitations on one hand, and the desire to reduce data variance on the other.

B.4.6.3 Correlation of Test Data with Theory

An effort should be made to correlate the field intensity data from B.4.6.2 with predictions of the field in the near-zone based on a mathematical model which adequately simulates the antenna and its environment. Since typical Naval aircraft have dimensions comparable to wavelengths at HF, they represent resonant structures with standing waves of voltages and currents over their surfaces. From the data in B.4.6.2b an effort should be made to compare positions along the wing where the observed voltages and currents are maximum with their predicted positions (antinodes) based on thick cylindrical antenna theory. Other comparisons may be suggested during the course of the tests to make the data more meaningful and useful.

B.4.6.4 Final Report

A comprehensive report on the entire test program, its results and conclusions, as well as those theoretical confirmations that are possible should be prepared. Recommendations as to minimum distances between transmitting antennas and refueling areas should be made if sufficient confidence and reliability in the data can be had.

B.4.7 Testing for X-ray Radiation Hazards from Electronic Equipment

The detection of X-radiation which is produced by electron tubes is more difficult than is the detection of radiation intentionally produced by X-ray equipment or by radioactive materials. One reason for this added difficulty is that an extremely strong electromagnetic radiation field is present along with the X-radiation. This electromagnetic field may result in the production of large gradients of potential within the particular detector and its circuitry, which could be responsible for considerable error in the indicated value of X-radiation intensity. Proper shielding of the detector and its circuitry against electromagnetic radiation may substantially reduce the error, but the amount of shielding required may attenuate lower-energy X-radiation, before it reaches the detector, to such an extent that the detector may be insensitive to the lower-energy X-rays. In the detection of X-radiation from electronic tubes this consideration is particularly important because energy values of X-radiation as low as 20 kiloelectronvolts must be detected.

Another reason for the additional difficulty of X-radiation from electron tubes lies in the fact that this radiation is generated in extremely high intensity pulses of very short time duration. The average value of X-radiation intensity is therefore relatively low. For example, a klystron operating at a duty cycle of 0.001 may produce an average dose rate of X-radiation of 1 roentgen per hour, at a distance of a few feet from the tube. The actual intensity in a single pulse of klystron operation may be in the order of 1000 roentgens per hour at the same distance, if the klystron operation were continuous instead of being pulsed. Such high instantaneous intensities result in erroneous indications from conventional gas-filled detectors of X-radiation, such as ionization chambers, rendering reliable operation difficult, if not impossible.

Additional difficulties which are encountered in the detection of X-radiation from RF tubes are caused by the size of the radiated beam, the resolution of the beam, and the energy response of the detector. The radiated beam from most electron tubes which emit X-radiation is small and well collimated, especially when the tubes are shielded. The beam escapes through small openings or faults in the tube body or shielding. If the beam is of high intensity but only 0.5 inch in diameter, it would obviously not completely cover the area of a 3-inch diameter ionization chamber. The roentgen has been defined as that amount of X-radiation which will produce, in one cubic centimeter of air at standard pressure and temperature, ions carrying one electrostatic unit (esu) of charge of either sign. The scale of the ionization chamber has been calibrated in accordance with this definition of the roentgen and, therefore, requires an X-radiation field which is uniform and which completely fills the cross-sectional area of the ionization chamber. Since a small beam will ionize only a small portion of the cross-sectional area, resulting in a much lower and, therefore, erroneous indication of measured intensity.

Small, battery-operated radiation meters are available which have been designed to measure X-radiation having energies from about 12 to 40 kiloelectronvolts in electromagnetic fields up to 10 milliwatts/cm^2.

Photographic dosimetry is an extensive use as a form of detection of X-radiation. Certain types of photographic films, when enclosed in a badge-type holder, may be used for personnel monitoring. Large films located in the vicinity of high power generators of X-radiation will indicate not only intensity levels, but also the distribution pattern of the radiation. Energy level measurements may be readily made by trained personnel if sufficient time and auxiliary equipment is available. Photographic films, particularly those types used in dosimeters, are insensitive to electromagnetic radiation. Detailed techniques and instrumentation for X-radiation detection and measurements may be found in NAVMED P-5055.

B.4.8 Testing for Hazards of EMR to Ordnance

Specific procedures have been developed by NAVORD and NAVAIR to evaluate the possibility of hazards to ordnance. The procedures detailed in NAVORD OP-3565/NAVAIR 16-1-529 NAVORD OD-30393, and OP-3565 shall be used to determine the presence of RADHAZ to ordnance.

B.4.9 Testing for Hazards from Lasers

The procedures in NAVMED P-5052-35 shall be used to determine the existence of possible hazards from lasers.

TEST REPORT

A test report should be prepared detailing results of the EMC survey. The test report should include the following details of testing:

a. Test plan.
b. Nomenclature of interference measuring equipment.
c. Date of last calibration of interference measuring equipment.
d. Detector functions used on interference measuring equipment.
e. Internal noise level of instrument at each detector function used at each test frequency.
f. Descriptions of procedures used.
g. Measured line voltages to test sample.
h. Test frequencies.
i. Method of selection of test frequencies.
j. Type of emissions measured.
k. Measured level of emission and susceptibility at each test frequency and test point.
l. Description and ambient profile data of interference free area.
m. Graphs showing items e., h., k., and l.
n. Photographs of test set ups and test sample.
o. Sample calculations (showing how item k. was obtained for each antenna used).
p. The system/installation should be completely identified in the test report. All suppression work performed during the tests should be fully described in words as well as by the test data in the report.

Figures B-3, B-4, and B-5 depict sample formats which may be used in the preparation of the report.

Table B-1. Antenna Types Used for EMC Testing

FREQUENCY RANGE	ANTENNA TYPE
14 kHz to 30 MHz	41 in. rod antenna with matching network
20 MHz to 200 MHz	Biconical,discone and dipole antennas
200 MHz to 10 GHz	Conical log-spiral,cavity-backed spiral and horn antenna
10 GHz to 40 GHz	Cavity-backed spiral and horn antennas

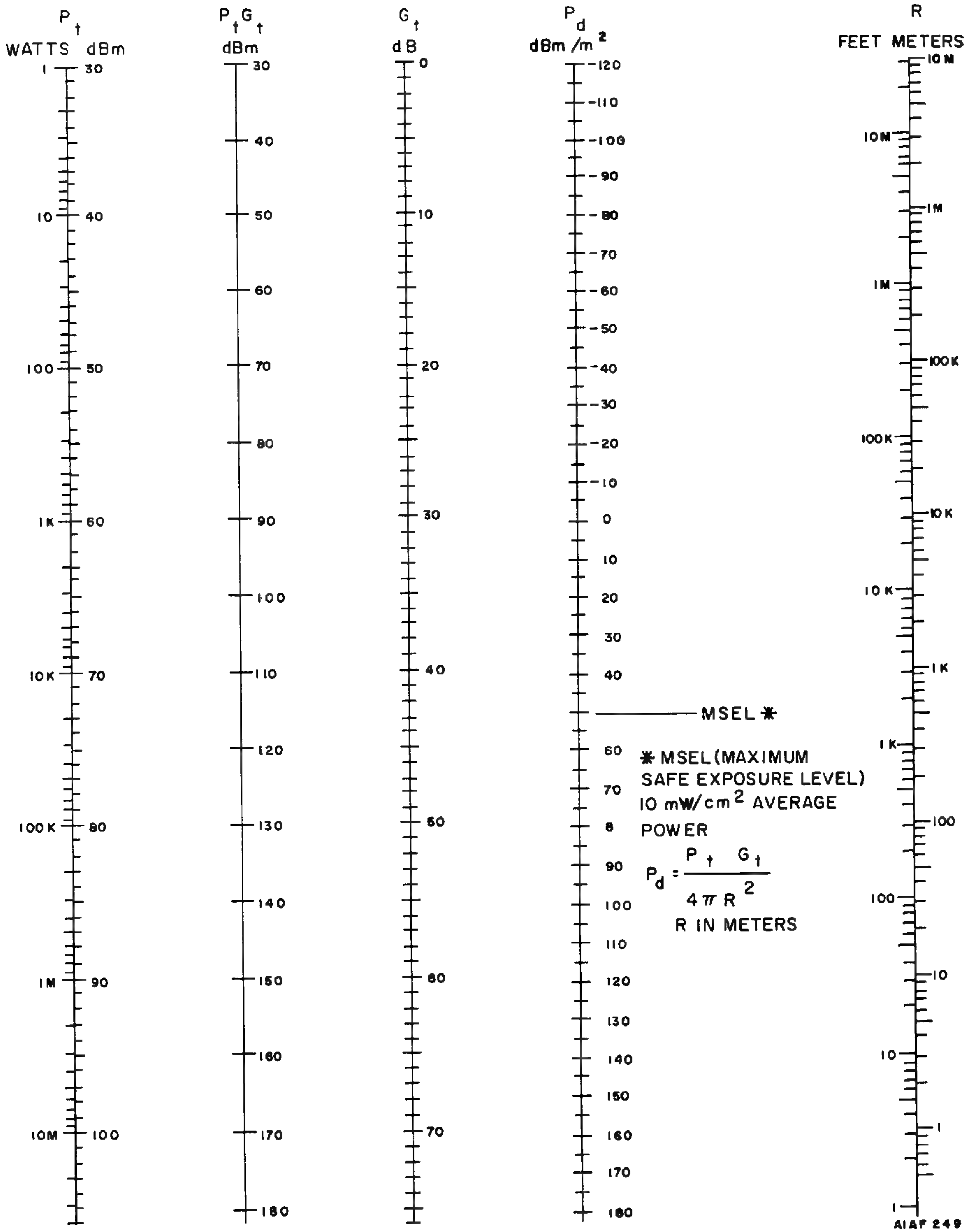


Figure B - 1. Power Density Nomogram (1 of 3)

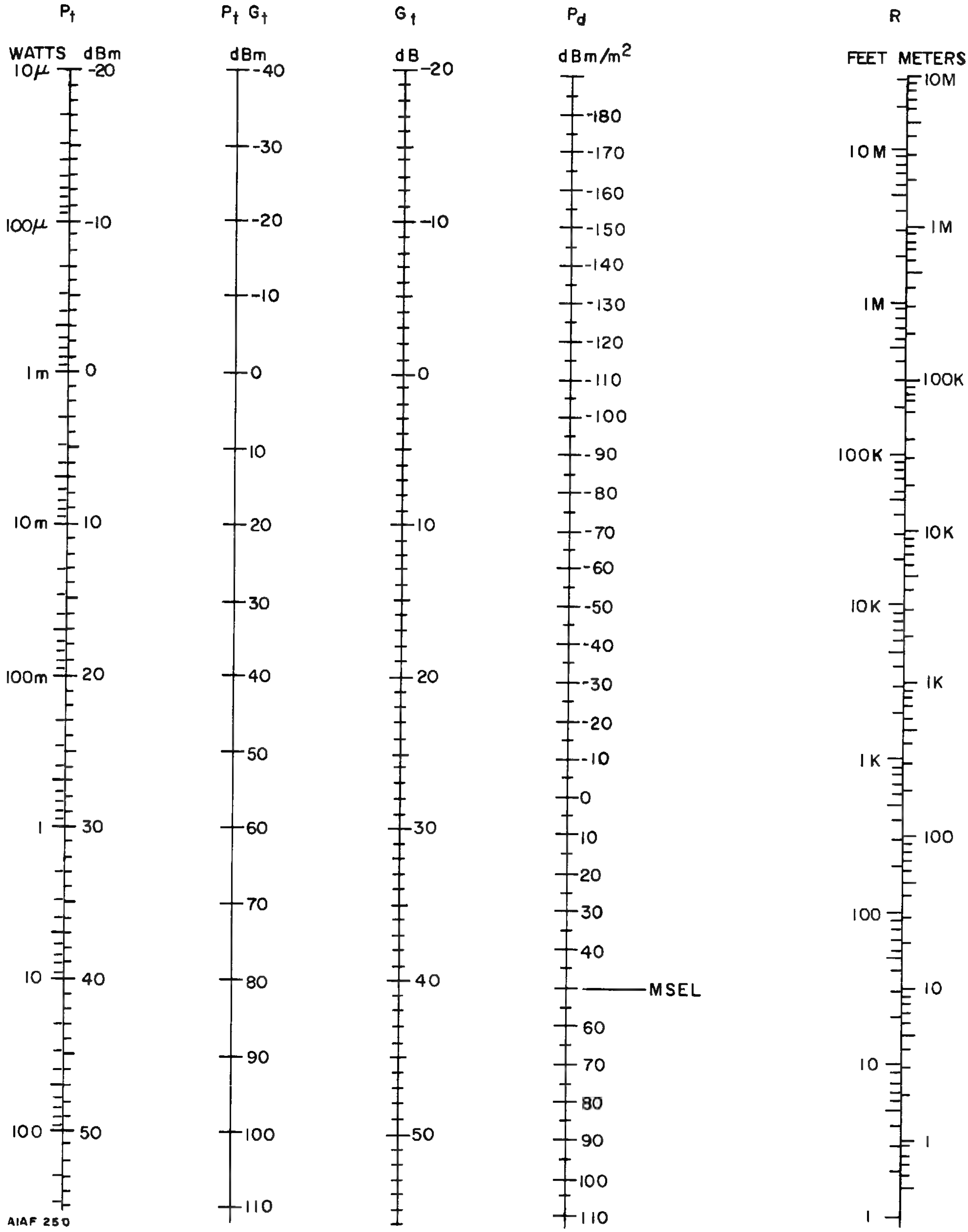


Figure B - 1. Power Density Nomogram (2 of 3)

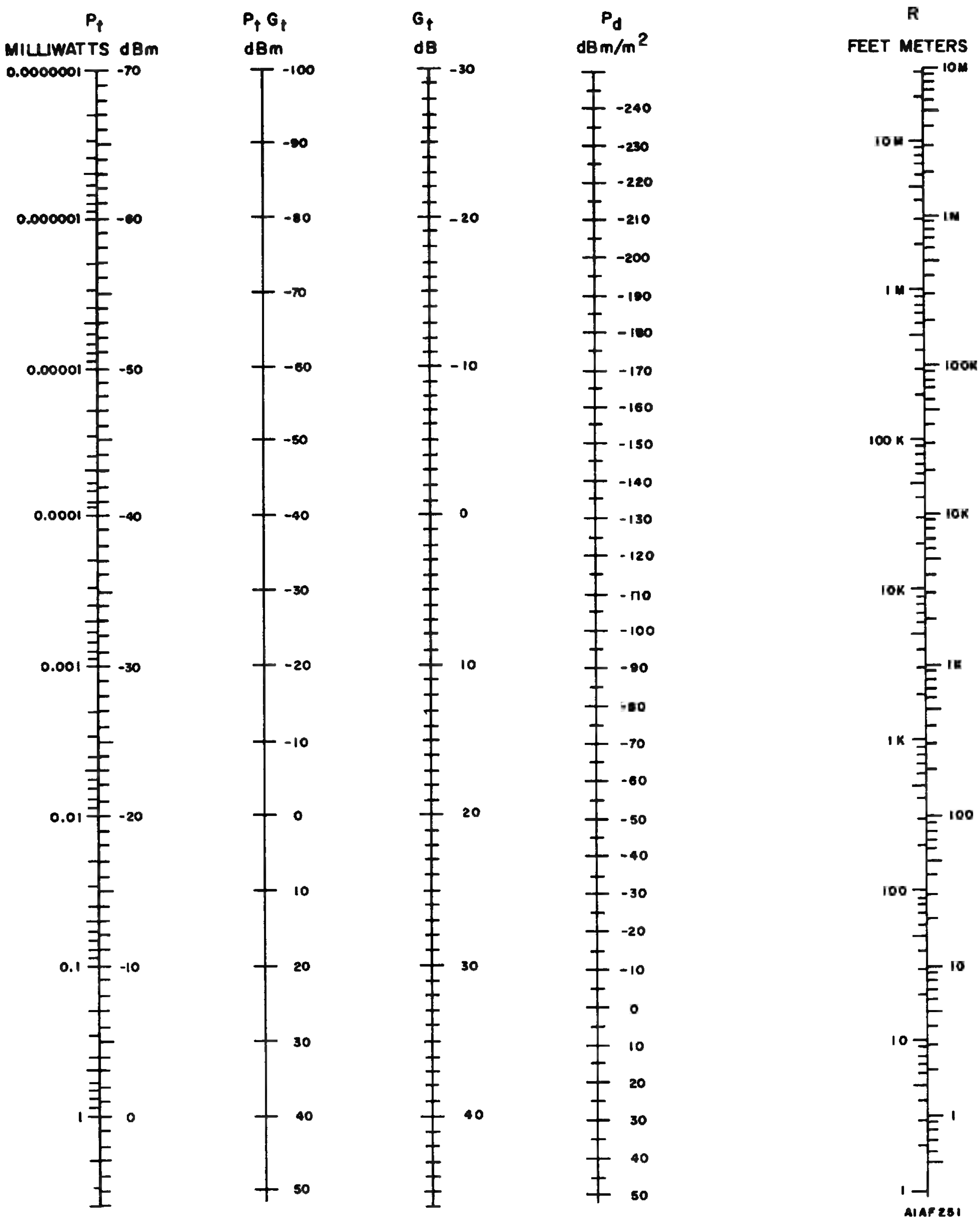


Figure B - 1. Power Density Nomogram (3 of 3)

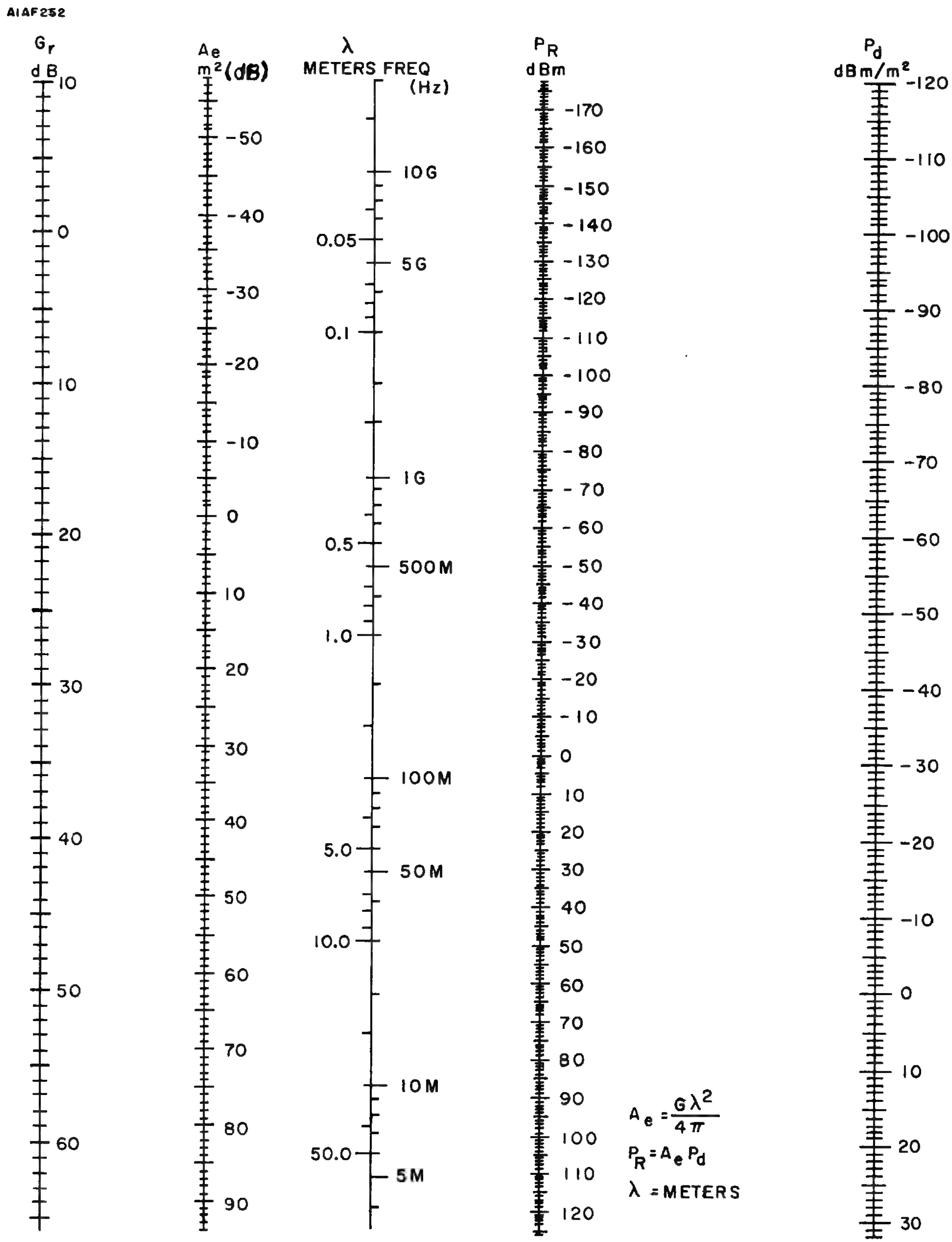


Figure B - 2. Effective Area and Received Power Nomogram

TEST EQUIPMENT LIST
DATA SHEET NO. ______

TEST PERFORMED	EQUIPMENT USED	SERIAL NO.	CALIBRATION DATA

AIAF253

Figure B-3. Susceptibility Sheet

SUSCEPTIBILITY DATA
SHEET NO. ______

EQUIPMENT UNDER TEST ______
SERIAL NUMBER ______
MODE OF OPERATION ______
SIGNAL GENERATOR USED ______
SERIAL NUMBER ______
FREQUENCY RANGE ______

TEST DATE ______
OPERATOR ______
WITNESS ______
TYPE OF TEST
RADIATED ☐
CONDUCTED ☐
LINE ______
TEST CONDITION ______

TEST FREQUENCIES	THRESHOLD SIGNAL LEVELS	OUTPUT LEVEL	DESCRIPTION OF RESPONSE

REFERENCE:
FIG. NO. ______

AIAF 264

Figure B-4. Equipment List

EMISSION DATA
SHEET NO.______

EQUIPMENT UNDER TEST______
SERIAL NUMBER ______
MODE OF OPERATION ______
TEST SET USED ______
SERIAL NUMBER ______
MEASUREMENT TECHNIQUE ______
DETECTOR FUNCTION ______
FREQUENCY RANGE ______
CORRECTION FACTOR =

TEST DATE ______
OPERATOR ______
TYPE OF TEST ______
RADIATED ☐
CONDUCTED ☐
LINE ______
TEST CONDITION ______

TEST FREQ. MC	METER READING DB	CORRECTION FACTOR DB	FINAL READING DB	REMARKS

REFERENCE:

FIG. NO.______

AIAF 255

Figure B - 5. Emission Data Sheet

APPENDIX C

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GLOSSARY

Following are the definitions of some of the more commonly used terms in the areas of Electromagnetic Compatibility and Electromagnetic Radiation Hazards.

Arc. An electrical discharge of relatively long duration which may be brought about by separating current-carrying electrodes or may result from a spark discharge between initially separated electrodes, provided that the energy source is sufficient to maintain the arc.

Athermal Effect. Any effect of electromagnetic absorption, exclusive of the production of heat.

BESEP. Acronym for "The Base Electronics System Engineering Plan," a planning tool used in the integration of electronic systems and shore/site facilities. One of the plan's considerations includes electromagnetic compatibility-radiation hazards.

Bonding. The process of physically connecting two metallic surfaces to provide a low impedance path for RF current.

Breakdown Voltage. The minimum potential necessary to produce an electrical discharge in a gaseous medium under stated conditions.

Direct Wave. See Ground Wave Propagation.

Distillation Range. Difference between the End Boiling Point and Initial Boiling Point of fuels, an indication of relative fuel volatility.

Dose. The amount of absorbed electromagnetic energy.

Electrical Equipment. Equipments which do not produce useful internal signals, or in which the electrical energy is not used for information purposes. Examples are electric motors, fluorescent lamps, office equipment, etc.

Electrolyte. A chemical compound which when fused or dissolved in certain solvents, usually water, will conduct an electric current. All acids, bases, and salts are electrolytes.

Electroexplosive Device (EED). Any single discrete unit, device, or subassembly whose actuation is caused by the application of electric energy which, in turn, initiates an explosive propellant, or pyrotechnic material contained therein. The term electro-explosive device does not include complete assemblies which have electric initiators as subassemblies, but includes only subassemblies themselves. The term is synonymous with electric initiator.

Electromagnetic Compatibility (EMC). The ability of communications-electronics (C-E) equipment, subsystems and systems to operate in their intended operational environments without suffering or causing unacceptable degradation because of unintentional electromagnetic radiation or response. It does not involve a separate branch of engineering, but directs attention to improvement of electrical and electronic engineering knowledge and techniques to include all aspects of electromagnetic effects.

Electromagnetic Environment. The composite electromagnetic field generated by natural and man-made sources existing in a transmission medium or in operational areas.

Electromagnetic Interference. Any emission, radiation, or induction which degrades, obstructs, or repeatedly interrupts the designed performance of electronic equipments.

Electronic Equipment. Equipments which produce useful internal signals, or serve functionally by generating, transmitting, receiving, storing, processing or utilizing information in the broadest sense. Examples are communications, radar, sonar, countermeasures, navigation, computers, test equipment, etc.

Electromagnetic Radiation. Emission of energy from a source in the form of electromagnetic waves.

Electromagnetic Susceptibility (EMS). The characteristic of electronic equipment that permits undesirable responses when subjected to electromagnetic energy.

EMC/EMR Hazard Program Plan. The guiding document outlining control, reduction, techniques and procedures to achieve EMC/EMR Hazard free operation and is included as part of the BESEP.

EMC/EMR Hazard Predictions. The process of determining potential interference conditions, or potential hazards by calculation and/or measurement of field strengths, equipment susceptibilities, propagation losses, frequency response characteristics, etc., as applicable.

Emission. Electromagnetic energy propagated from a source by radiation or conduction.

Emission, Broadband. That which has a spectral energy distribution sufficiently broad, uniform, and continuous so that the response of the measuring receiver in use does not vary significantly when tuned over a specified number of receiver impulse bandwidths.

Emission, Conducted. Desired or undesired electromagnetic energy which is propagated along a conductor. Such an emission is called "conducted interference" if it is undesired.

Emission, Counterpoise. The reference-plane portion (grounded or ungrounded) of an unbalanced antenna.

Emission, Narrowband. That which has its principal spectral energy lying within the bandpass of the measuring receiver in use.

Emission, Radiated. Radiation and induction field components in space.

Emission Spectrum. The power vs. frequency distribution of a signal about its fundamental frequency which includes the fundamental frequency, the associated modulation sidebands, as well as non-harmonic and harmonic spurious emissions and their associated sidebands.

Field Strength. The term "Field Strength" is applied only to measurements made in the far field. The measurement may be of either the electric or the magnetic component of the field, and may be expressed as V/m, A/m, or W/m^2; any one of these may be converted to others. It is abbreviated as FS. For measurements made in the near field, the term "Electric Field Strength" (EFS) or "Magnetic Field Strength" (MFS) is used, according to whether the resultant electric or magnetic field, respectively, is measured. The EFS is expressed as V/m, and the MFS as A/m. In this field region, the field measured will be the resultant of the radiation, induction and quasi static ($1/r$, $1/r^2$ and, if present, the $1/r^3$) components, respectively, of the field where r is the distance from the source. Inasmuch as it is not generally feasible to determine the time and space phase relationships of the various components of this complex field, the energy in the field is similarly indeterminate.

Fraunhofer Region or Zone. That volume of space extending beyond the far-field distance. The far-field distance is defined as equal to $2D^2/\lambda$ where D is the maximum antenna aperture dimension and λ is the fundamental frequency wavelength. In the Fraunhofer region, antenna radiation patterns are essentially independent of the distance r from the aperture, the field strength decays as $1/r$, power density decays as $1/r^2$ and for all practical purposes, the electromagnetic field may be regarded as composed of plane waves.

Free Space Transmission. An idealized state in which both transmitting and receiving antennas are isolated in unbounded, empty space.

Frequency Allocation. The term, frequency allocation, generally refers to the apportionment or sectioning of the radio frequency spectrum into bands or blocks, with each band being reserved for a specific use category.

Frequency Assignment. The term, frequency assignment, generally refers to the assignment of a specific frequency within a band or block to an individual user.

Frequency Management. The application of technical criteria, management techniques, options, etc., to the optimization of the supply and demand on the frequency spectrum.

Frequency Spectrum. The range of frequencies of electromagnetic energy encountered by man from both natural phenomena and man-made sources; generally extends from less than .001 hertz to greater than 10^{22} hertz. The Radio Frequency Spectrum is, loosely, that portion of the total spectrum used for information communication.

Fresnel Region or Zone. That portion of the radiation field, for large aperture antennas, lying between a wavelength from the antenna and a distance r defined by: $r<KD^2/\lambda$, where D is the maximum antenna aperture dimension, λ is the fundamental frequency wavelength and K is a constant.

Galvanic Corrosion. Galvanic or two-metal corrosion occurs when two dissimilar metals in contact or otherwise connected electrically are exposed to a corrosive electrolyte.

Gamma Radiation. Electromagnetic radiation of nuclear origin, occupying an intermediate position between X-Radiating and Cosmic-Radiation in the frequency spectrum.

Grounding. The process of physically providing a metallic surface with a low resistance or impedance path to ground potential.

Ground Reflected Wave. See Ground Wave Propagation.

Ground Wave Propagation. Generally, ground wave propagation refers to the transmission of energy which does not make use of reflections from the ionosphere. Ground waves may take a direct or reflected course from the transmitter to the receiver, or they may be conducted to the surface of the earth or reflected in the troposphere. The resulting ground wave, therefore, may be composed of one or more of the following components: the direct wave, the ground-reflected wave, the surface wave, and the tropospheric wave.

Insertion Loss. A guide to the use of capacitors in suppression applications. Insertion loss is the ratio of the voltages existing across the circuit load impedance before and after connecting the suppression capacitor into the circuit. Insertion loss data, in decibels (dB), indicates the voltage across the circuit load impedance that will be reduced by the insertion of the suppressor capacitor.

Interference. See Electromagnetic Interference.

Interference Margin. A quantity which represents the amounts of energy by which an undesirable signal exceeds the level required to produce interference. It is calculated by combining source, transmission, antenna, and susceptibility factors, to determine the total contribution to a potential interference condition.

Ionizing Radiation. Electromagnetic waves or particular emanations capable of causing ionization, i.e., the ejection of electrons from atoms.

Isotropic Antenna. A hypothetical antenna which radiates or receives equal energy in all directions.

Magnetic Field. A state or region influenced by a charge or system of charges in which moving charges, or charged bodies, are subject to forces by virtue of both their charges and motion.

Microwaves. A term used loosely to identify radio waves in the frequency range from about 1.0 GHz upwards.

Polarization. Term used to describe the orientation of the time varying electric or magnetic field vector. If the vector is confined to a plane containing the direction of propagation of the wave, the wave is plane polarized. If the vector rotates around the direction of propagation as an axis but remains constant in magnitude, the wave is circularly polarized. If the amplitude does not remain constant, so that the end of the vector traces out an ellipse, the wave is elliptically polarized.

Power Density. The power flow per unit area, usually expressed in milliwatts per square centimeter. Average power density is the quantity relating to the heating properties of electromagnetic radiation and, hence, to personnel and other hazards, while peak power density becomes important in the study of the effects of electromagnetic fields on electrically initiated explosive devices and on fuel hazards.

Propagation. The transmission of electromagnetic energy.

Radiac. Name given to the detection, identification, and computation of nuclear radiation.

Radio Frequency Interference. See Electromagnetic Interference.

Roentgen. The basic unit used to indicate a measured quantity of ionizing radiation. It is a measure of the ionization in air caused by X- or gamma-radiation, and is defined as that amount of radiation that will produce $2.083 X 10^9$ ion pairs in 1 cc of air under standard conditions.

Shielding or Shield. A housing, screen, or other object which substantially reduces the effect of electromagnetic fields on one side thereof, upon devices or circuits on the other side.

Skin Effect. A phenomenom in which high frequency currents tend to concentrate in a thin layer or skin on the surface of conductors.

Sky-wave Propagation. The transmission of electromagnetic energy which depends upon, and makes use of, reflections from the layers in the ionoshpere.

Spark. An electrical discharge of relatively short duration.

Spectrum Signature. The package of data which describes the electromagnetic radiating and receiving characteristics of electronic equipment.

Spurious Emission. Emissions on a frequency or frequencies which are outside the designed or necessary bandwidth, and the level of which may be reduced without affecting the corresponding transmission of intelligence. These include harmonics, parasitic emissions, and intermodulation products, but exclude unnecessary modulation sidebands of the fundamental frequency.

Spurious Response. Any response of an electronic device to energy outside its designed reception bandwidth.

Squibb. An electro-explosive device.

Susceptibility. See Electromagnetic Susceptibility.

Thermal Effect. Generally refers to the heating effects of electromagnetic radiation on materials and people.

Vapor Pressure. The pressure of a confined body of liquid, e.g., fuel in storage tanks.

X-Radiation. Electromagnetic radiation of short wavelength, usually produced by the bombardment of a metal target by high-energy electrons.

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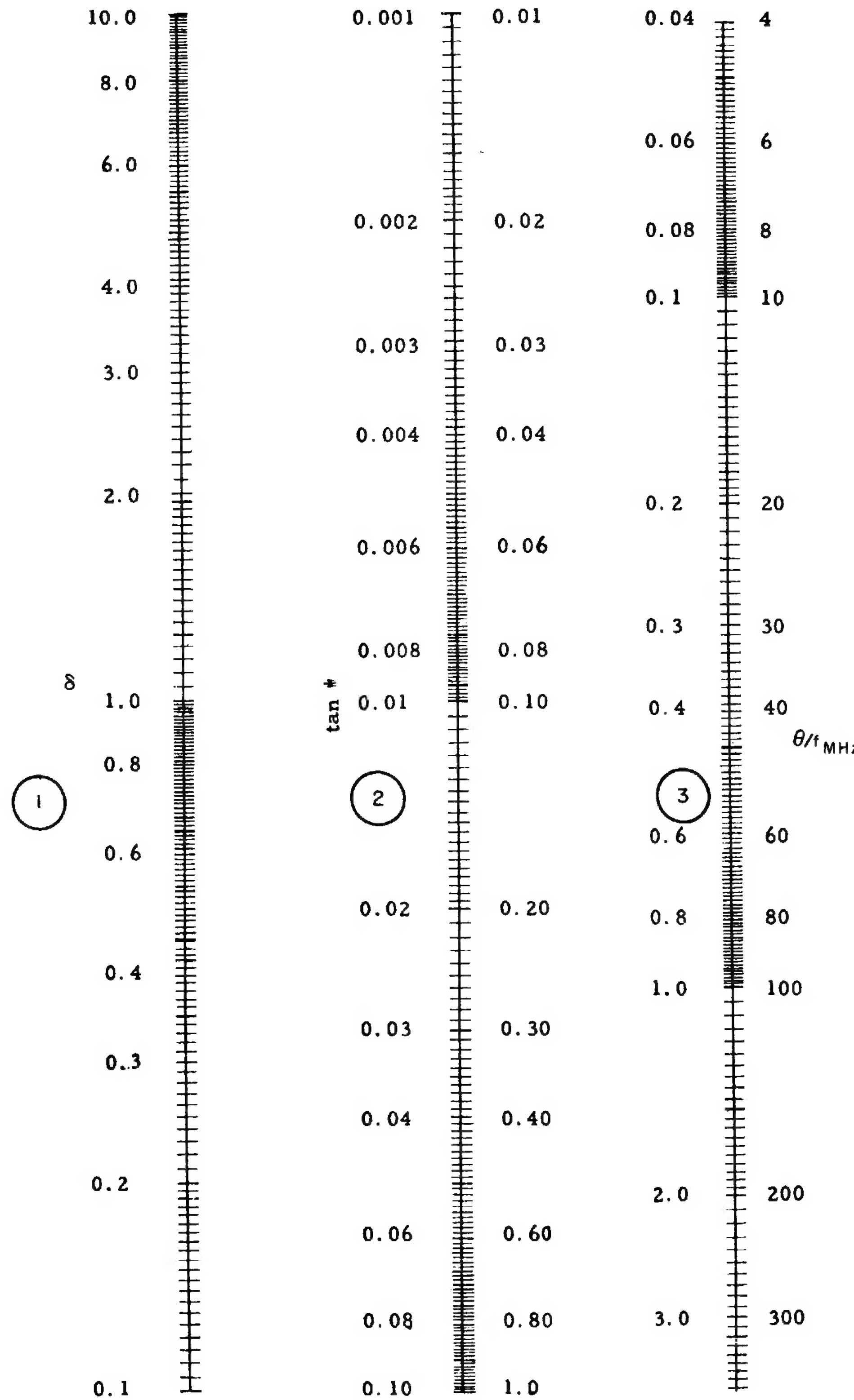
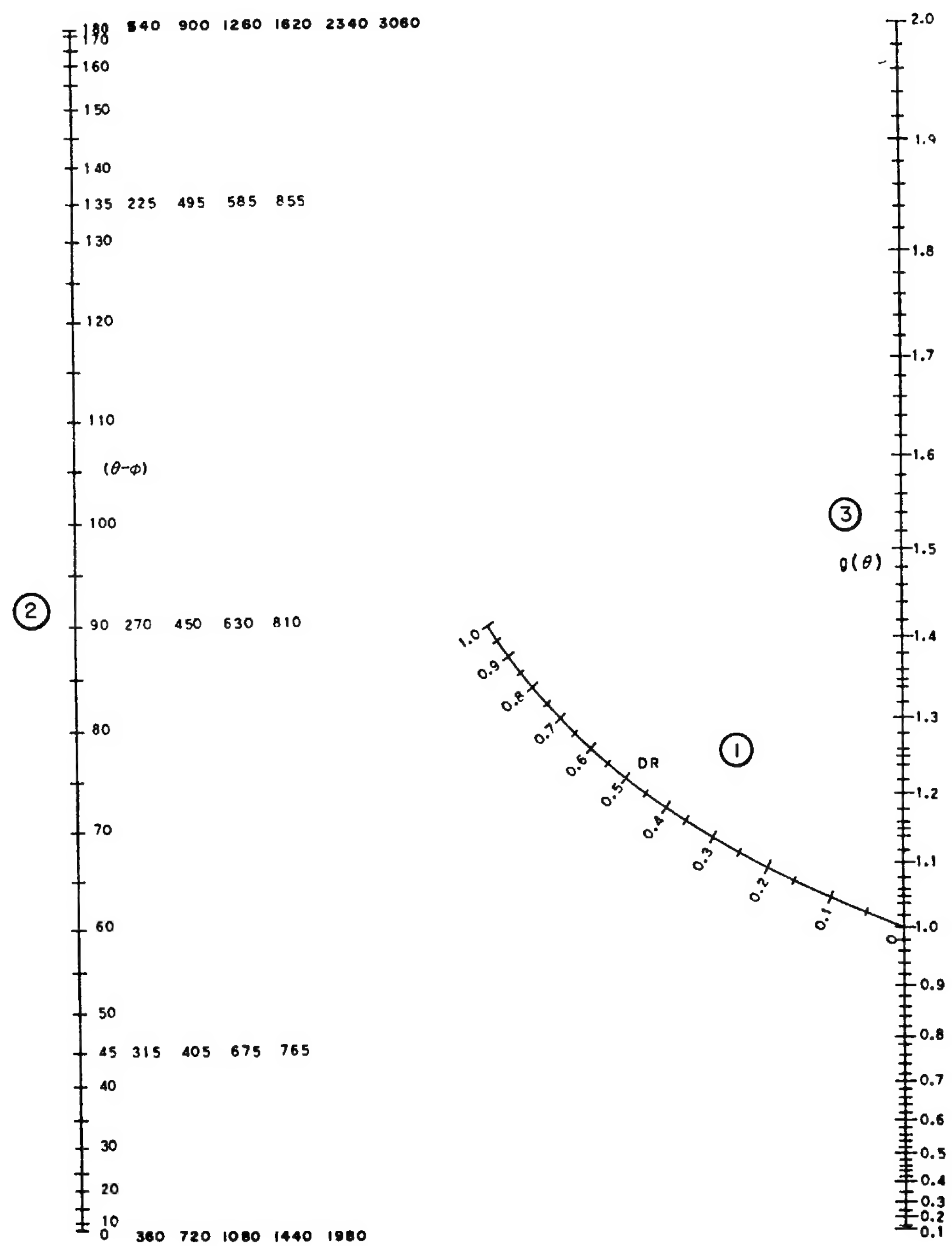


A. Nomogram for Determining θ/f_{MHz}



B. Nomogram for Determining g(θ)

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Figure FO6 - 1. Nomograms,
Referenced in Figure 6 - 26,
Lines 3.2.1 and 3.4